Table 5.--The storms used to develop PMP depth-duration and depth-area curves for the Tennessee River watershed.

Storm Number	Location	Date	6-hr 1-mi^2 Precipitation (in.)	Storm Duration (hr.)
1	Thrall, TX	9/8-10/21	23.4	24
2	Cheyenne, OK	4/3-4/34	20.0	18
3	Woodward Ranch, TX	5/31/35	-	10
4	Keene, OH	8/6-7/35	11.3	24
5	Simpson, KY	7/4-5/39	21.8	12
6	Baldwin, ME*	8/21/39	-	3
7	Hallett, OK	9/5-6/40	18.9	24
8	Plainville, IL*	5/22/41	-	2
9	Smethport, PA	7/17-18/42	30.7	24
10	Larchmont, NY	7/26-28/42	6.21	24
11	Iowa City, IA	9/8/42	6.0	6
12	Gering, NB	6/17-18/43	10.0	10
13	Glenville, WV	8/4-5/43	14.9	9
14	Stanton, NB	6/12-13/44	15.5	24
15	Jerome, IA	7/16-17/46	8.7	24
16	Holt, MO	6/22-23/47	12.2	10
17	Stromburg, NB	6/26-27/48	8.2	18
18	Dumont, IA	6/25/51	9.4	12
19	Clear Spring, MD	7/22-23/53	11.0	18

*Not considered in figure 17

on a moisture or rainfall gradient. The "latitudinal gradient chart" for the mountainous east was developed as shown in figure 18. The latitudinal gradient chart, based on observed rainfall gradients due primarily to sheltering by mountains, implicitly incorporates moisture effects.

While observed rainfall gradients satisfactorily defined the variation in PMP estimates in the mountainous east, an assessment of moisture parameters was required to adequately define the PMP gradient over the remainder of the basin. The moisture adjustment charts (fig. 19 and 20) were made from an assessment of mean and extreme dew points. Dodd's charts (1965) provided the information on mean dew points, while maximum persisting 12-hr dew points developed in the Hydrometeorological Branch (Environmental Data Service, 1968) provided the source of maximum dew points. These dew point sources were supplemented by a survey of high dew point situations affecting the Tennessee area during the period of 1956-1965. From several situations, an outstanding period from July 26, 1956 to August 6, 1956, was selected for analysis. Mean dew points for stations in and around Tennessee were averaged for this period. The result is shown in figure 21. All station dew points were reduced moist-adiabatically to 1000 mb before being plotted and analyzed. This 12-day period consisted of recurring high dew points and is considered representative of a persisting high dew point situation that precedes and accompanies extreme summer rainfall occurrence. No evidence has been found in recent dew point data that this situation has since been exceeded.

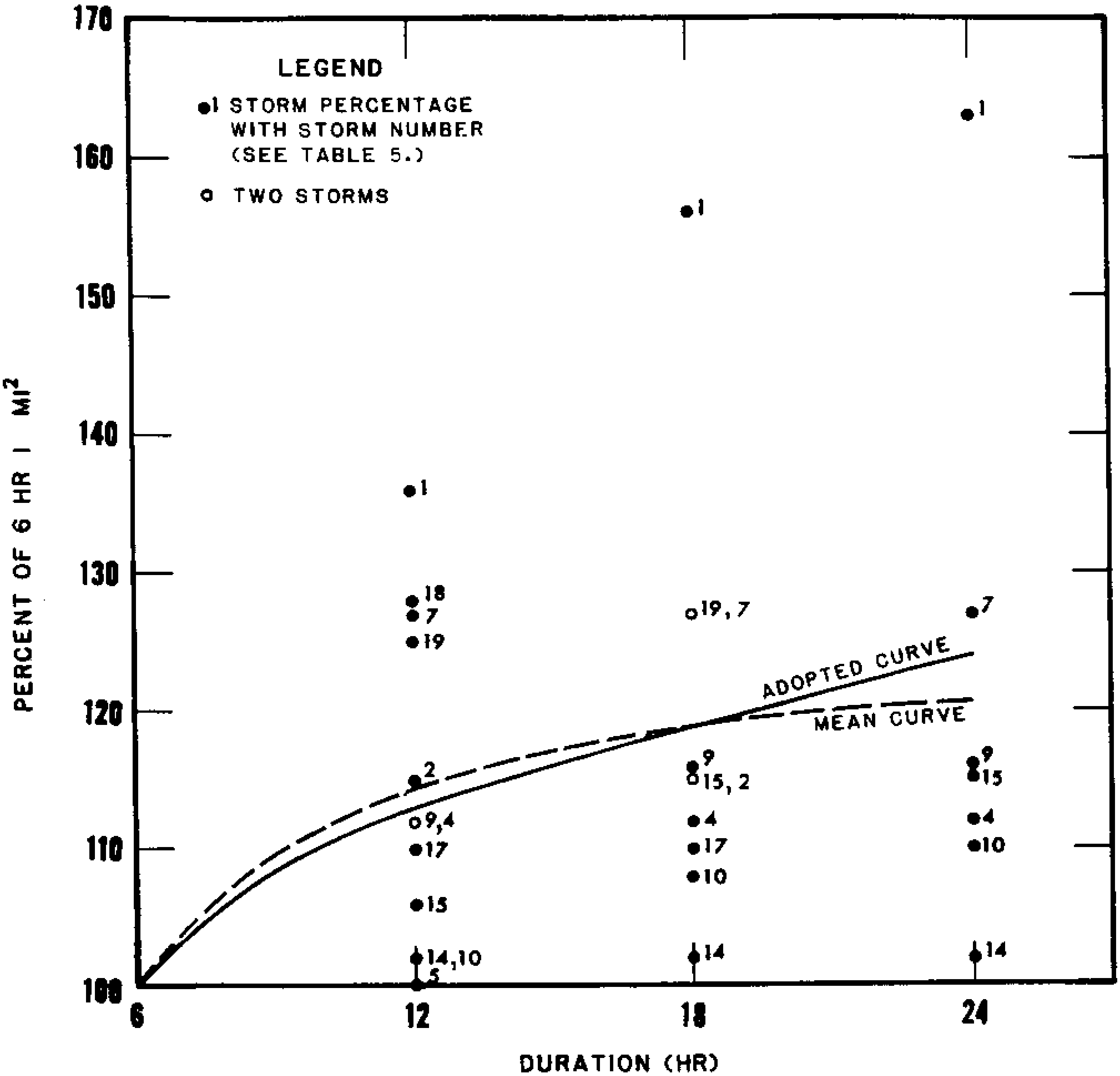


Figure 17.--Adopted small basin PMP depth-duration curve with supporting data.

The various analyses support a regional dew point gradient of about 2°F from the southwestern to the northeastern portion of the basin. This corresponds to a difference in rainfall of 10 percent, based on the usual model for convective rain during extreme storms (U.S. Weather Bureau 1947). Figure 19 shows the moisture index lines in percent for the western portion of the basin, while figure 20 covers the nonmountainous eastern part.

The moisture adjustment percentage lines of figure 20 and the latitudinal gradient percentage lines of figure 18 for the east have similar but not identical values at their boundary, as they derive from different concepts. This

Table 6.—1-mi² PMP and TVA precipitation values from 5 min to 24 hr

Duration	PMP (rough)	PMP (int.)	PMP (smooth)	Duration	PMP (rough)	PMP (int.)	PMP (smooth)
5 min.	3.4	3.2	2.9	7 hr	38.8	37.2	35.7
10 min	5.9	5.4	5.0	8 hr	39.8	38.2	36.6
15 min	8.1	7.4	6.8	9 hr	40.7	39.0	37.3
20 min	9.8	9.1	8.4	10 hr	41.3	39.6	37.9
25 min	11.3	10.6	9.8	11 hr	41.8	40.1	38.4
30 min	12.6	11.8	11.1	12 hr	42.3	40.6	38.9
35 min	13.8	13.0	12.3	13 hr	42.8	41.0	39.3
40 min	14.9	14.1	13.3	14 hr	43.2	41.4	39.7
45 min	15.8	15.1	14.3	15 hr	43.6	41.8	40.0
50 min	16.7	16.0	15.2	16 hr	43.9	42.1	40.9
55 min	17.5	16.8	16.0	17 hr	44.2	42.4	40.6
60 min	18.2	17.4	16.7	18 hr	44.5	42.7	40.9
2 hr	25.1	24.2	23.2	19 hr	44.9	43.0	41.2
3 hr	29.2	28.0	26.9	20 hr	45.2	43.3	41.5
4 hr	32.5	31.2	29.9	21 hr	45.5	43.6	41.8
5 hr	35.2	33.8	32.4	22 hr	45.8	43.9	42.1
6 hr	37.4	35.9	34.4	23 hr	46.1	44.2	42.4
				24 hr	46.4	44.5	42.6

Table 6. 1-mi² PMP and TVA precipitation values from 5 min to 24 hr (continued).

Duration	TVA (rough)	TVA (int.)	TVA (smooth)	Duration	TVA (rough)	TVA (int.)	TVA (smooth)
5 min	2.0	1.6	1.2	7 hr	22.3	20.5	18.7
10 min	3.6	3.0	2.4	8 hr	22.9	20.0	19.2
15 min	5.0	4.2	3.5	9 hr	23.4	21.4	19.5
20 min	6.0	5.2	4.5	10 hr	23.8	21.8	19.8
25 min	6.8	6.2	5.5	11 hr	24.1	22.1	20.1
30 min	7.5	6.9	6.3	12 hr	24.4	22.4	20.4
35 min	8.2	7.6	7.0	13 hr	24.7	22.6	20.6
40 min	8.9	8.3	7.7	14 hr	24.9	22.8	20.8
45 min	9.5	8.9	8.3	15 hr	25.1	23.0	21.0
50 min	10.0	9.4	8.8	16 hr	25.3	23.2	21.2
55 min	10.5	9.9	9.3	17 hr	25.5	23.4	21.3
60 min	11.0	10.4	9.7	18 hr	25.7	23.6	21.5
2 hr	14.7	13.6	12.5	19 hr	25.9	23.8	21.7
3 hr	17.3	15.9	14.5	20 hr	26.1	24.0	21.8
4 hr	19.2	17.6	16.0	21 hr	26.3	24.2	22.0
5 hr	20.6	18.9	17.2	22 hr	26.5	24.4	22.2
6 hr	21.6	19.8	18.1	23 hr	26.7	24.5	22.3
				24 hr	26.8	24.6	22.4

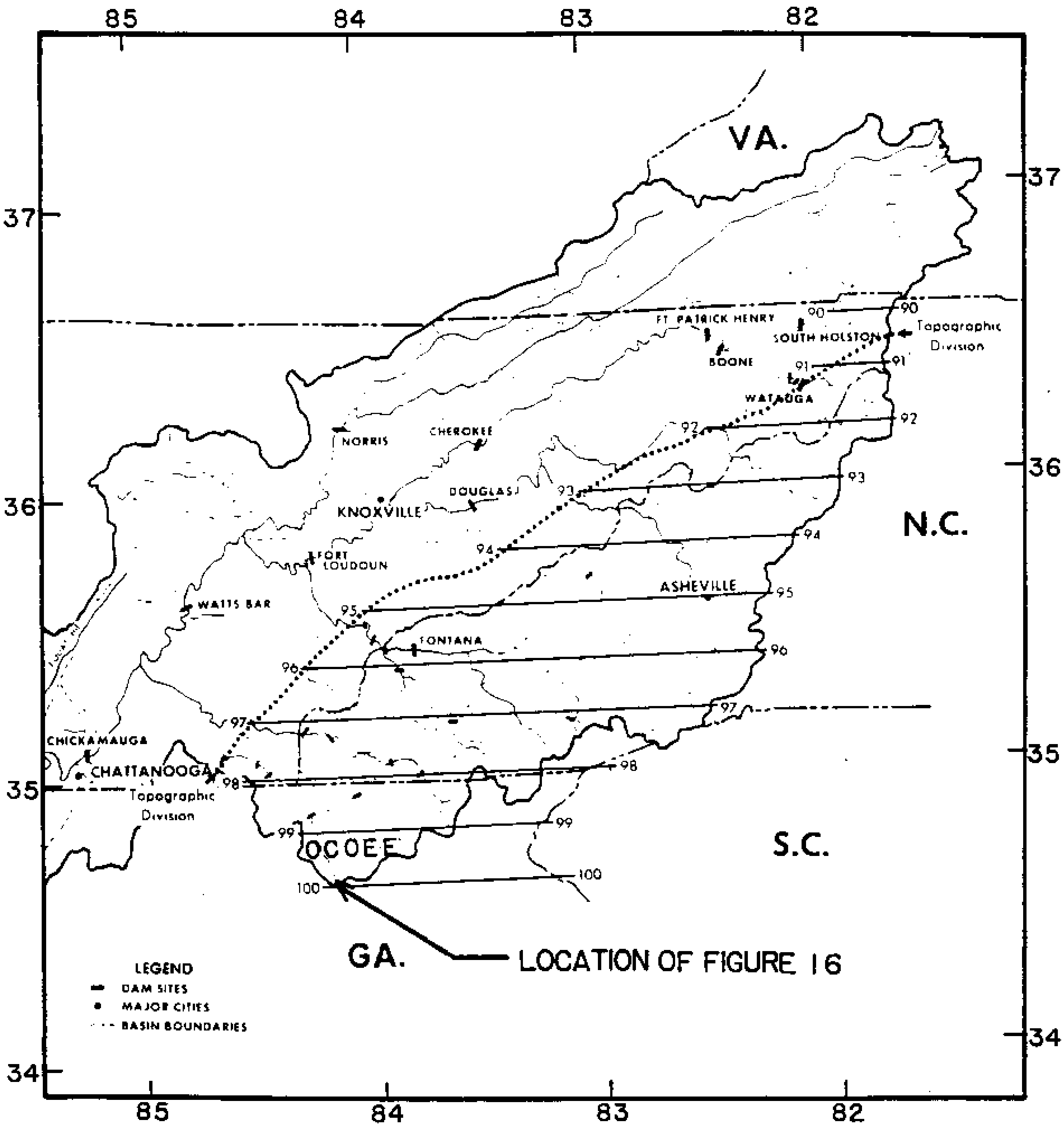


Figure 18.--Broadscale sheltering (in percent) by mountainous complex of eastern Tennessee River watershed.

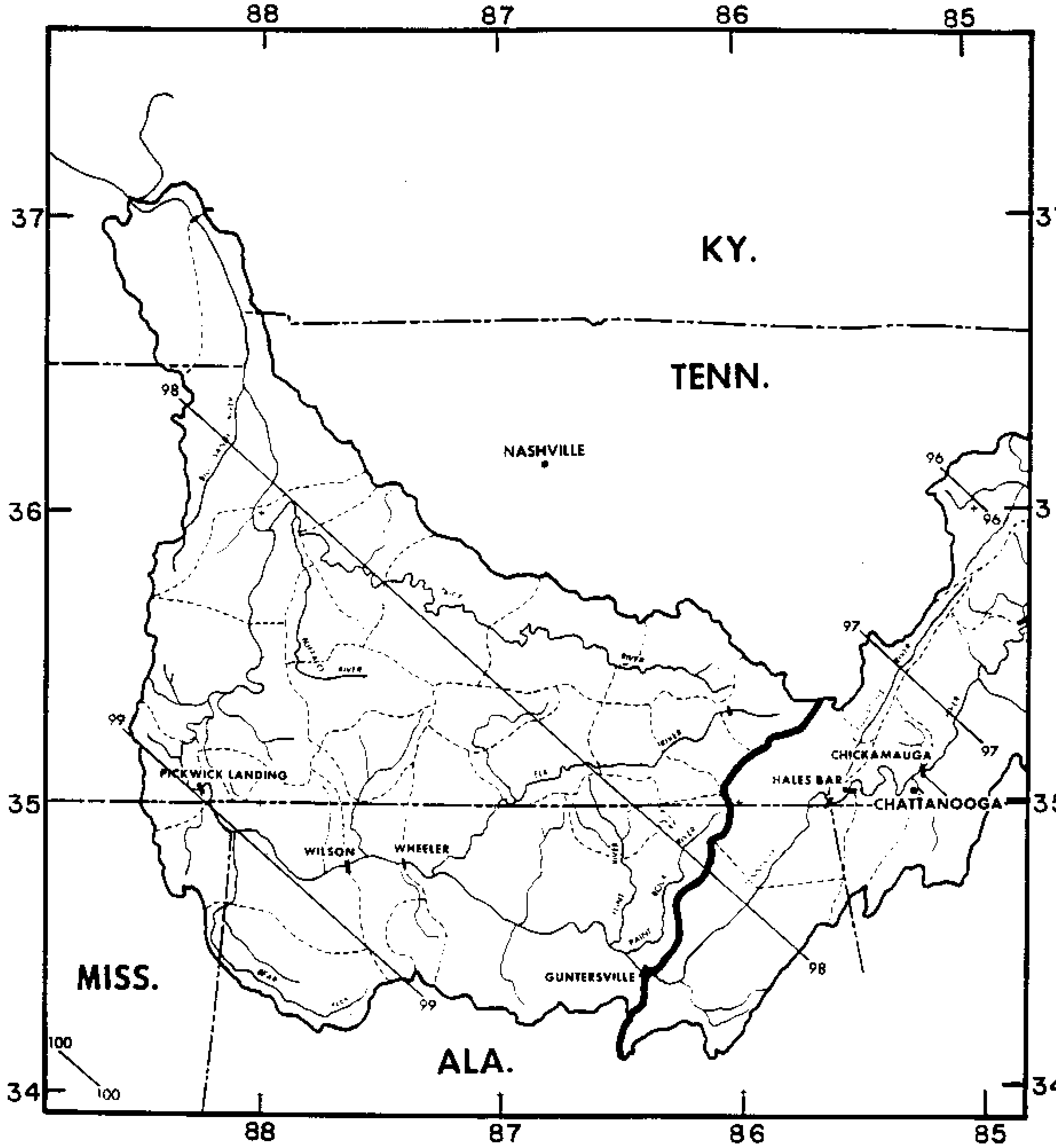


Figure 19.--Moisture index chart (in percent) - western half of Tennessee River watershed (note overlap of eastern region shown in fig. 20).

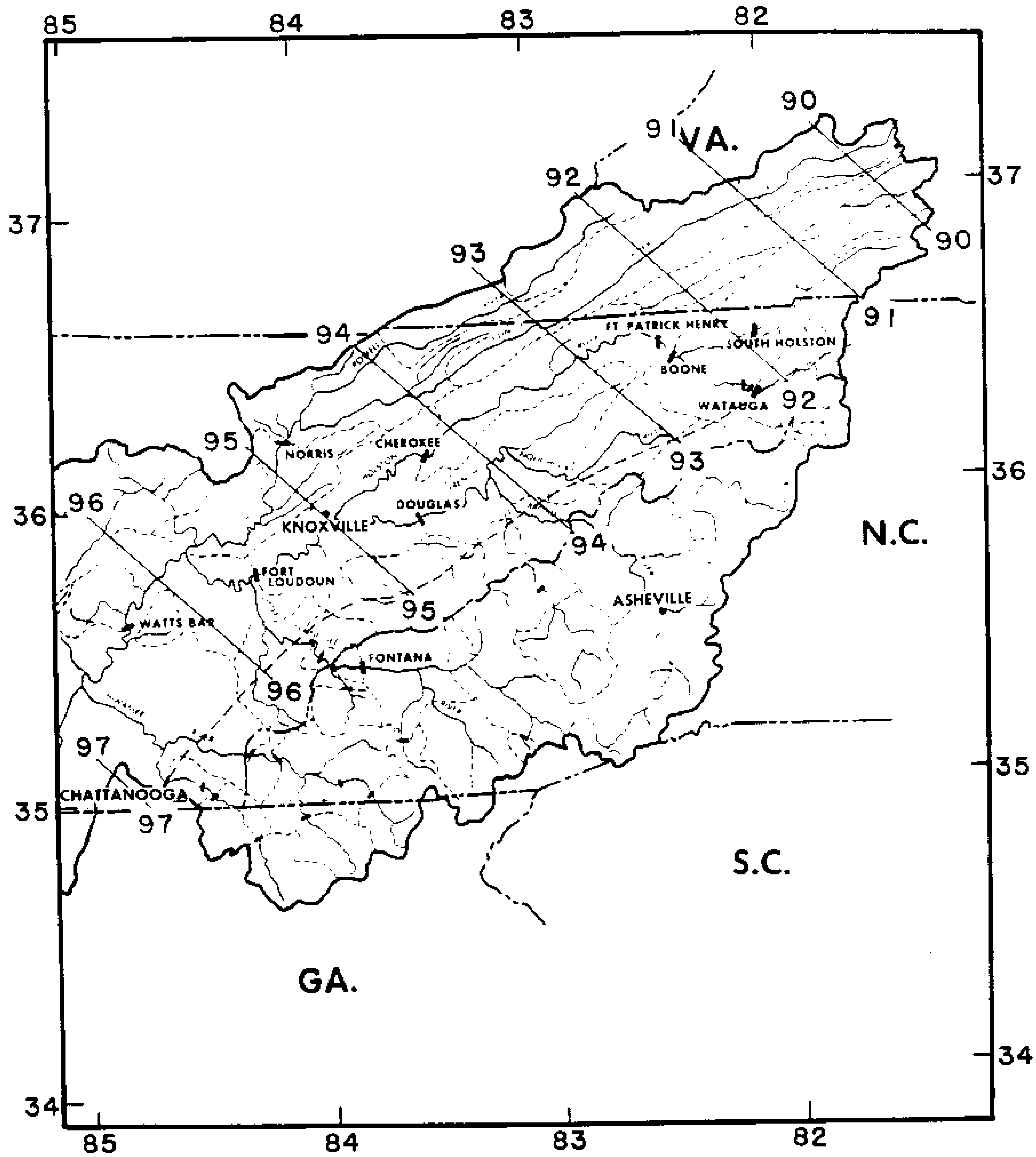


Figure 20.—Moisture index chart (in percent) - eastern half of Tennessee River watershed.

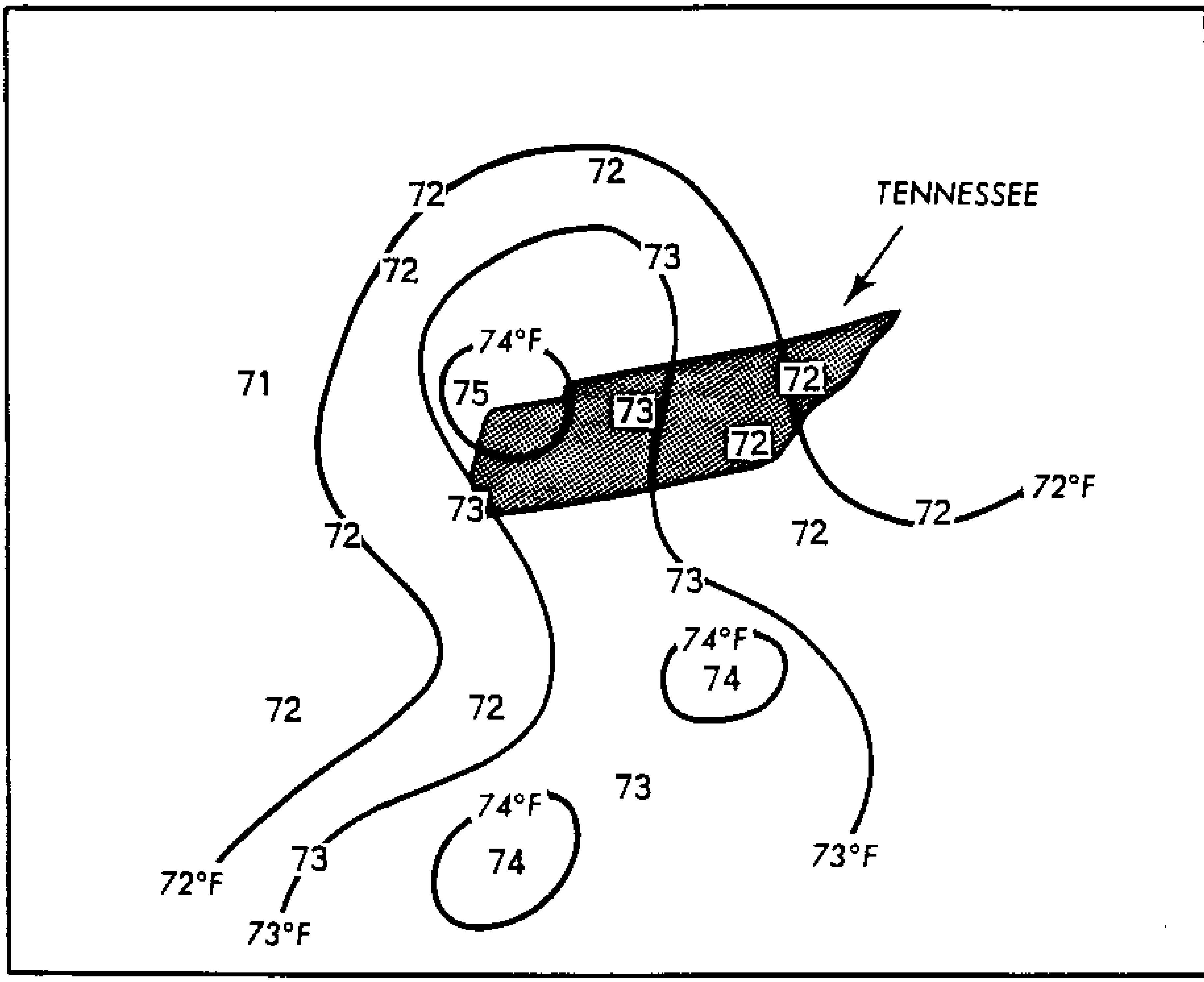


Figure 21.--Mean dew points for high moisture inflow situation of July 25-August 6, 1956.

discontinuity is taken care of by smoothing in the final precipitation index maps, figures 22 to 25. A single percentage map without discontinuities, while esthetically pleasing, would have little additional practical significance and therefore was not constructed.

2.2.9 Precipitation Index Maps for 6 hr 1 mi^2

The charts and concepts discussed previously were used to develop 6-hr 1-mi^2 index maps of PMP (figs. 22 and 23) and TVA precipitation (figs. 24 and 25).

2.2.9.1 Probable Maximum Precipitation. 6-hr 1-mi^2 PMP values from figure 16 of 34.4, 35.9 (by interpolation), and 37.4 in. were assigned to smooth, intermediate and rough terrain categories, respectively, at the southwestern edge of the basin. These were then adjusted over the western and central portion of the basin by multiplying by the moisture adjustment percents of figures 19 and 20. A value was computed for each 7 1/2-min quadrangle (sect. 2.2.3). and multiplied by the moisture adjustment percents of either figure 19 or 20. Isohyets of 6-hr 1-mi^2 PMP were then constructed, placing the steepest gradient in the vicinity of the most important changes in elevation. While these gradients may appear artificial, the approach nevertheless provides a reasonable placement of the maximum gradient, i.e., near the edges of the Cumberland Plateau.

Table 7. Ratios for adjusting 6-hr 1-mi² TVA precipitation depths to values for other durations

Duration (hr)	1	2	3	6	12	18	24
Ratio	0.51	0.68	0.80	1.00	1.13	1.19	1.24

In the mountainous east (classified rough), a basic 6-hr "rough" PMP value of 37.4 in. was assigned the southern edge of the basin (i.e., at the point of contact with the 100 percent line of fig. 18). This was progressively reduced to the north by means of the percentage lines of figure 18. The topographic adjustments, such as for the "first upslope" (sect. 2.2.3 and fig. 14) were then applied to the reduced values. With some smoothing the basic PMP index charts, figures 22 and 23, were obtained. Note that in figures 22 and 23 some of the isohyets are labeled in tenths. This is because the orographic adjustments described in detail in sections 3.5.2 and 3.5.3 are computed to the nearest five hundredths (.05). These orographic adjustments are "built into" the 6-hr 1-mi² PMP values in figures 22 and 23. Because of the accuracy with which the total orographic adjustments are computed, it is necessary to round the isohyet labels to the nearest tenths.

2.2.9.2 Tennessee Valley Authority Precipitation. The 6-hr 1-mi² TVA precipitation index charts, figures 24 and 25, are developed in an identical manner to the PMP index map. The basic values of 18.1, 19.8 and 21.6 in. for 1 mi² over "smooth," "intermediate," and "rough" surfaces, respectively, were determined from figure 15. For the mountainous east, the 21.6 in. ("rough" classification) was placed at the 100 percent line of figure 18.

2.2.9.3 Ratios of 6-hr 1-mi² TVA Precipitation to Other Durations. The generalized charts of TVA precipitation (see fig. 24 and 25) provide values for the 6-hr duration. To obtain values for other durations, it is necessary to use the relationships given in figure 15 to find ratios to compute values for other durations. For convenience, these ratios are shown in table 7 for the most common durations.

2.2.10 Depth-Area Relations

Basic 1-mi² PMP and TVA precipitation are adjusted for size of basin up to 100 mi² according to the adopted reduction factors shown in figure 26. To develop the depth-area curves in figure 26, depth-area curves from several important storms outside the Tennessee River watershed were analyzed. These storms are listed in table 5 and their five basic characteristics are mentioned in section 2.2.7.2.

In selecting the particular storms in table 5, the basic premise was that the storm most likely to be the candidate PMP storm for small basins and short durations in the Tennessee River watershed would be a thunderstorm occurring between April and September. All the storms in table 5 are of this type, occurring in regions and terrain similar enough to some portion of the Tennessee River Valley that they could have occurred in a meteorological sense just as easily in the Tennessee River watershed.

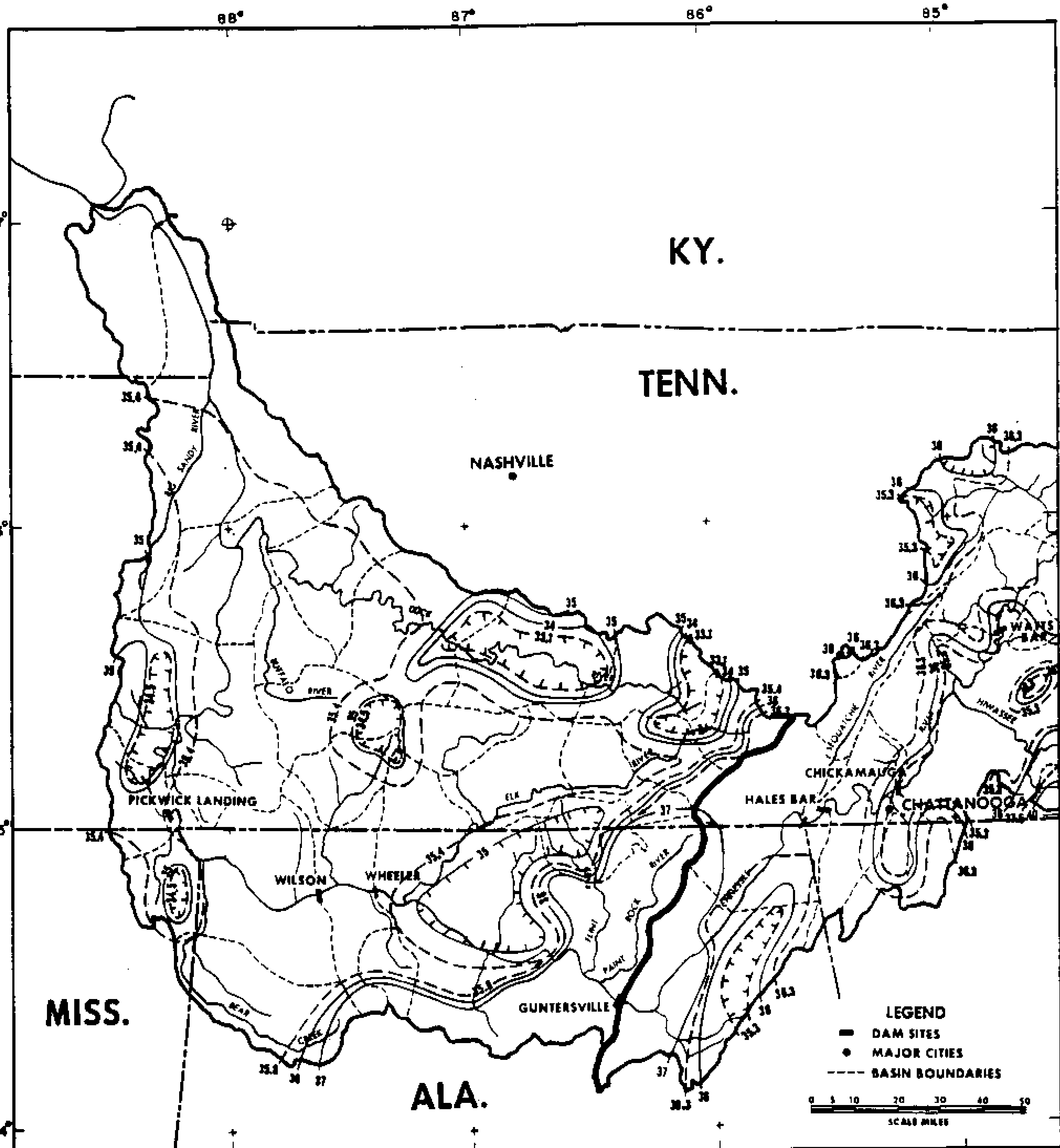


Figure 22.-- 6-hr 1-mi[2] PMP (in.)-western half of Tennessee River watershed (note overlap of eastern region in fig. 23).

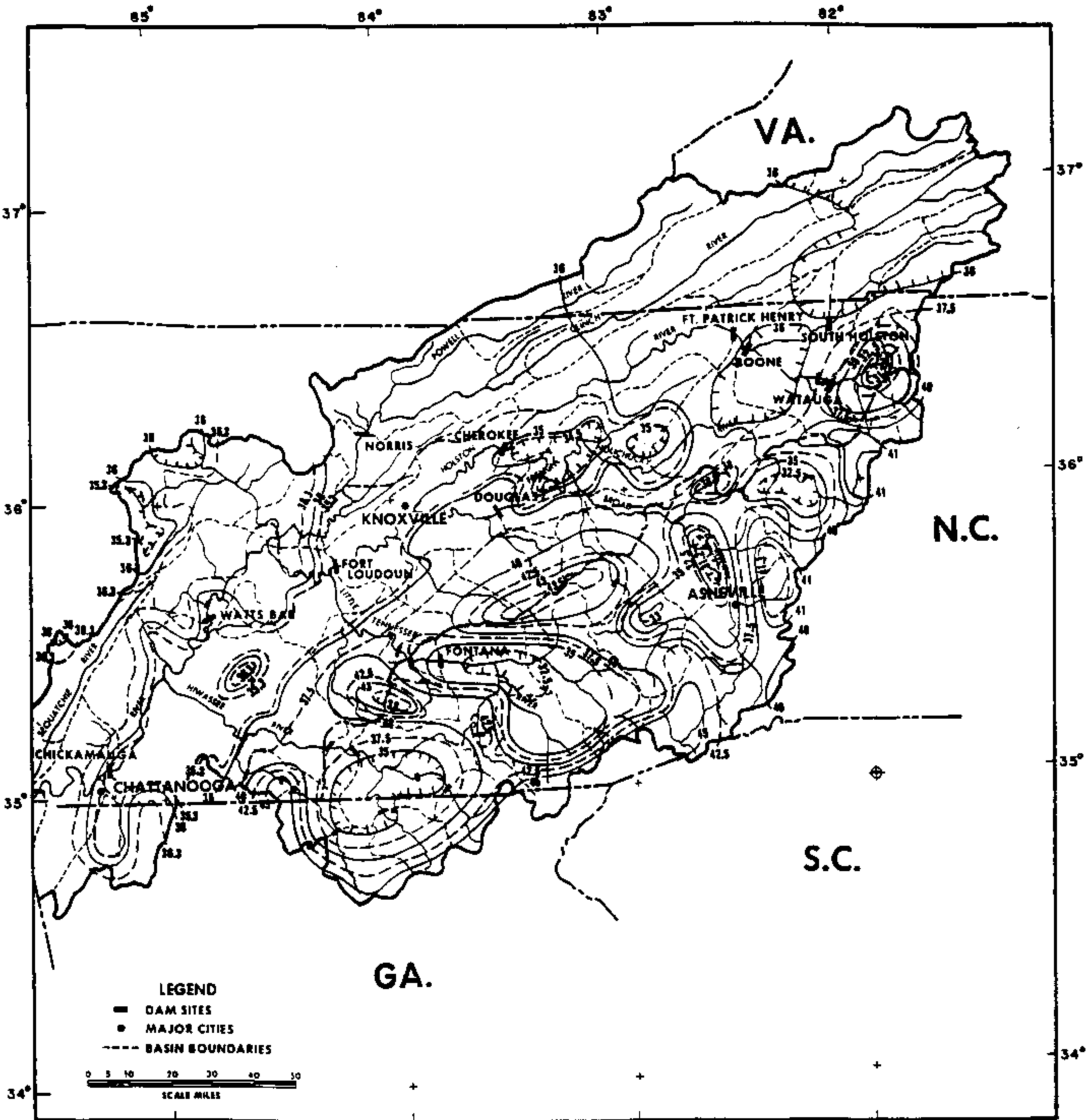


Figure 23.—6-hr 1-mi^2 PMP (in.)—eastern half of Tennessee River watershed.

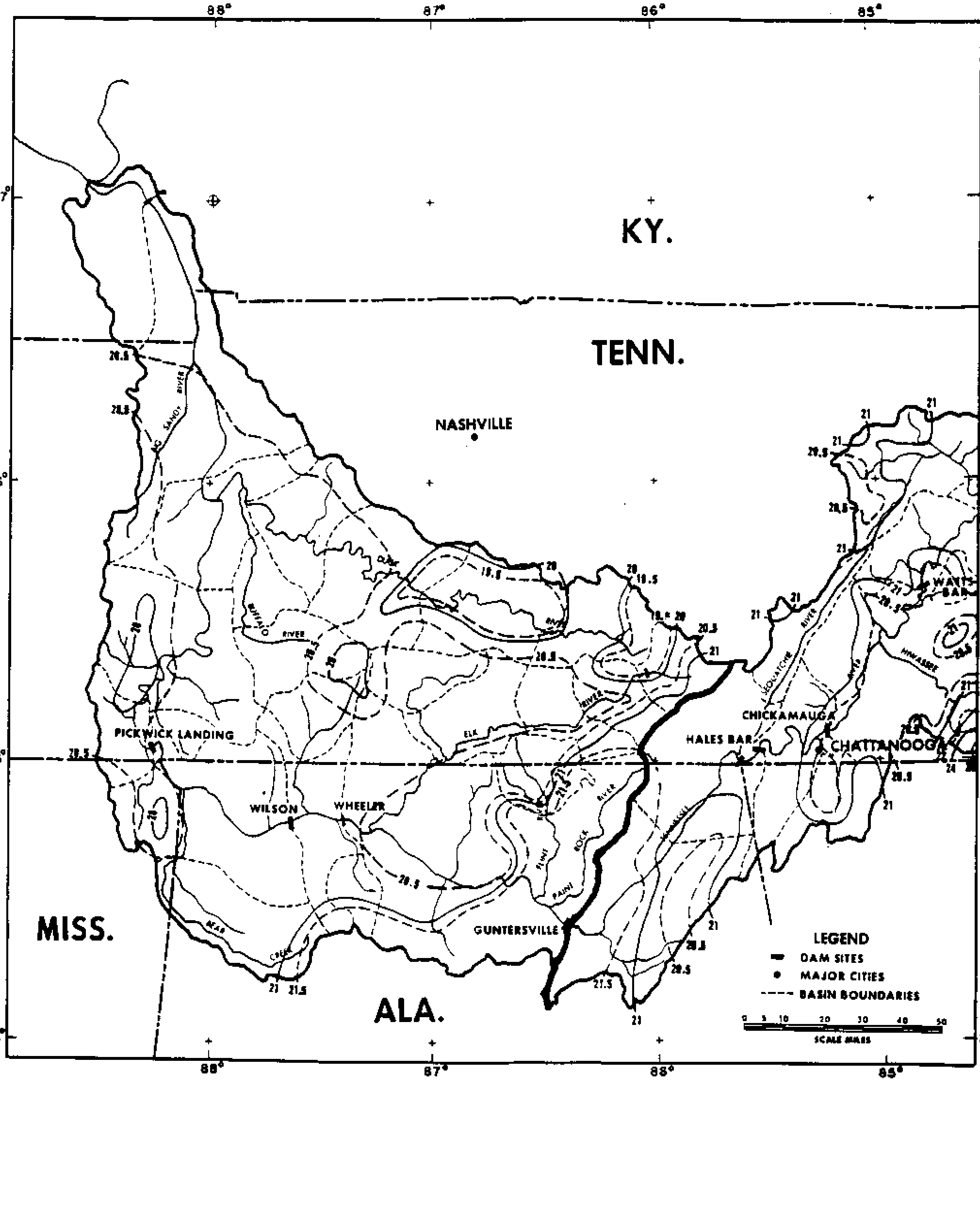


Figure 24.--6-hr 1-mi^2 TVA precipitation (in.)-western half of Tennessee River watershed (note overlap of eastern region in fig. 25).

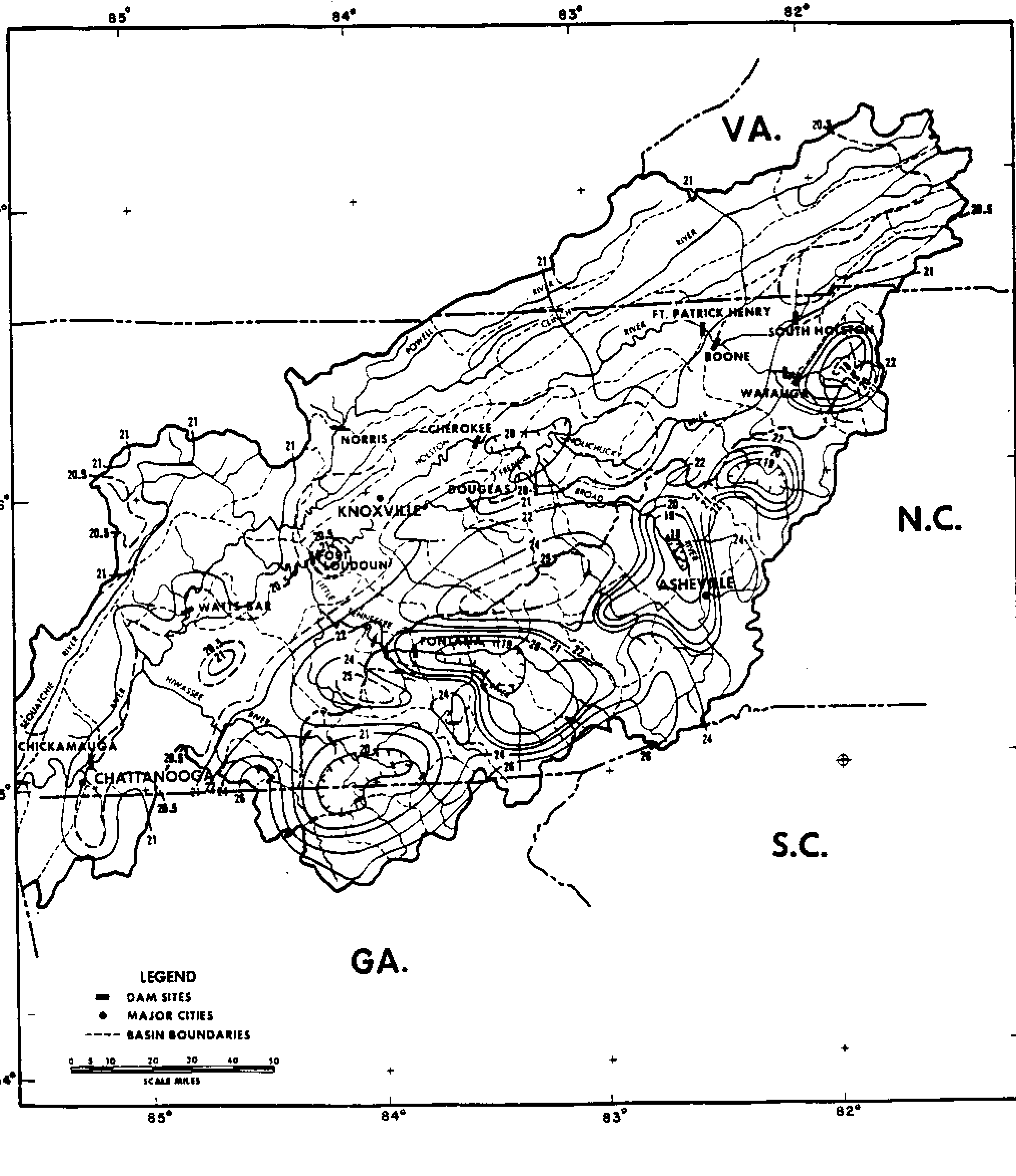


Figure 25.--6-hr 1-mi^2 TVA precipitation (in.)-eastern half of Tennessee River watershed.

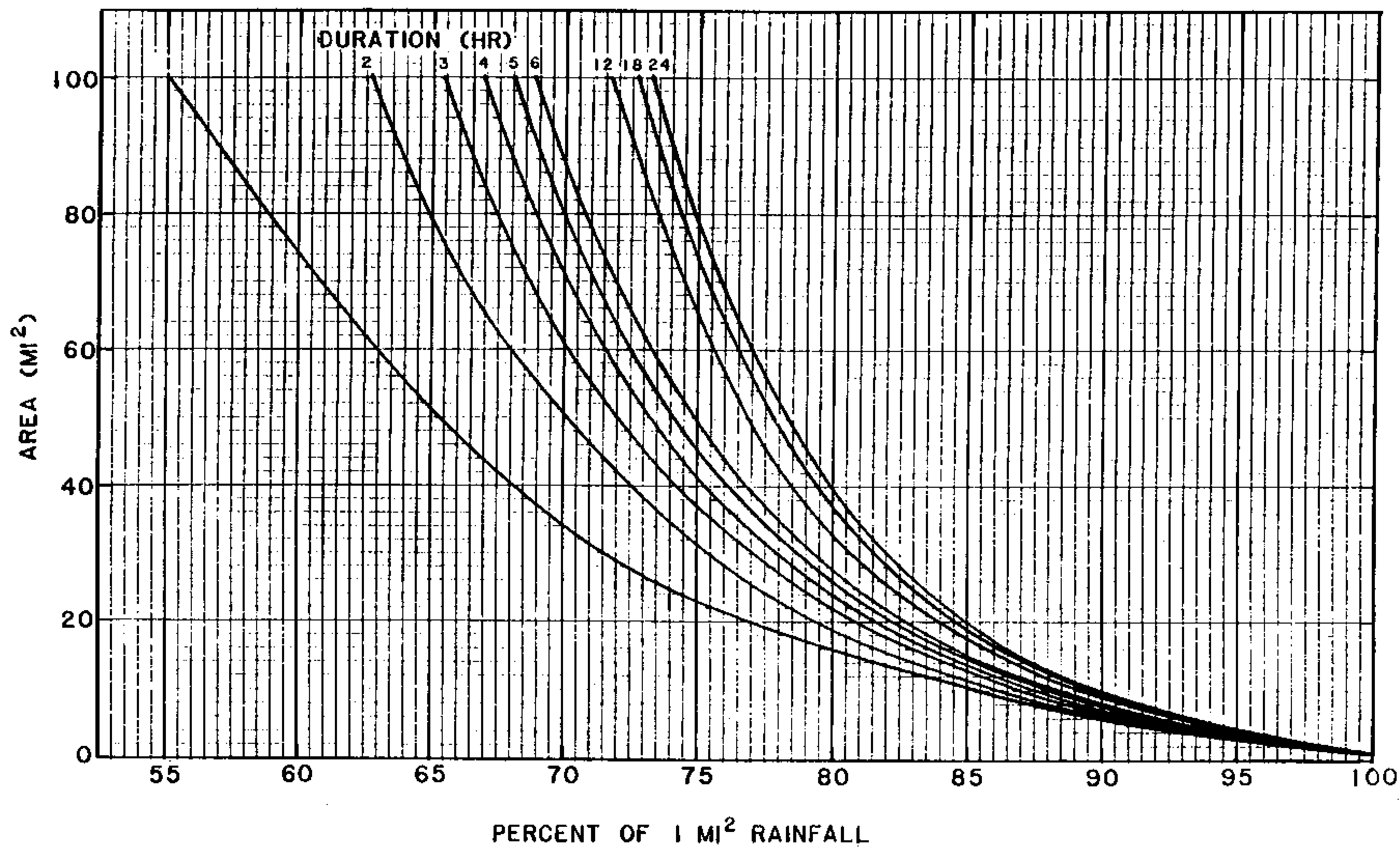


Figure 26.--Depth-area relations for small-basin estimates.

In order to derive the depth-area relations, each storm in table 5 was analyzed for durations of 1, 3, 6 and 24 hr (if data were available at any, or all of these durations). For each duration, area size vs. percentage of 1-mi^2 depth was plotted for each storm. In drawing the final depth-area curves at 1, 3, 6 and 24 hr, an attempt was made to draw as close as possible to the mean percentage of all storms at each duration. It was concluded that sufficient maximization was present in developing the index maps. For the depth-area reduction, therefore, representative curves would be appropriate. However, in order to ensure that the depth-duration, as well as depth-area curves, were both smooth and consistent for area sizes up to 100 mi^2, some adjustments to the depth-area curves for individual durations were necessary. This is illustrated in figure 27 for the 3-hr duration. The adopted curve varies only a few percent from a curve drawn through the mean of the data. Once the curves at 1, 3, 6 and 24 hr were established, depth-duration curves at various area sizes were drawn in order to obtain depth-area curves at the other durations (2, 4, 5, 12 and 18 hr). Data from storms in both "smooth" and "rough" regions were included in the development of the depth-area curves. Therefore, the adopted curves apply to both "rough" and "smooth" depth-duration relations. In addition, the adopted curves apply to both PMP and TVA precipitation, even though no storms from the Tennessee River watershed (table 1) were used in the depth-area analysis. This is because few, if any, Tennessee River watershed storms exceeded 6 hr in duration.

Figures 28 and 29 show the depth-area curves for some of the more significant storms of table 1 compared to the adopted curve for a duration of 3 hr. The approximate duration of the rainfall is indicated in the parentheses for each storm shown.

Figure 30 shows the adopted 3-hr depth-area curve along with similar curves from a few of the more significant storms outside the basin, including the Smethport storm. The adopted 3-hr curve from HMR No. 39 (Schwarz 1963) is also shown, since this was derived from a somewhat similar assessment of outstanding thunderstorm occurrences.

2.2.11 Variable Depth-Duration Criteria for TVA Precipitation, Index Value 19.8 in.

Storm events show considerably different depth-duration characteristics. In observed general storms, the ratio of 24-hr to 6-hr precipitation varies with the critical length of the storm. Such observed relations are preserved in the TVA precipitation criteria. It is desired to obtain a depth-duration curve characteristic of a storm of given duration. Thus, if for a particular basin a 12-hr total storm period is critical, the 3-hr rain to be used is not the extreme 3-hr rain, but rather a maximum 3-hr rainfall increment that is characteristic of a 12-hr storm.

Depth-duration data for 3-, 6-, 12- and 24-hr storms were compiled from Storm Rainfall in the United States (U.S. Army 1945 -) and other sources (Hershfield 1961 and U.S. Weather Bureau 1966). Figure 31 shows adopted TVA precipitation depth-duration curves based on these data for storm durations of 3 to 24 hr. Any of these curves applies directly to any basin where the 6-hr 1-mi^2 TVA precipitation is 19.8 in. (fig. 24 and 25 "intermediate" classification). Treatment of the full range of index values is covered in section 2.2.12.

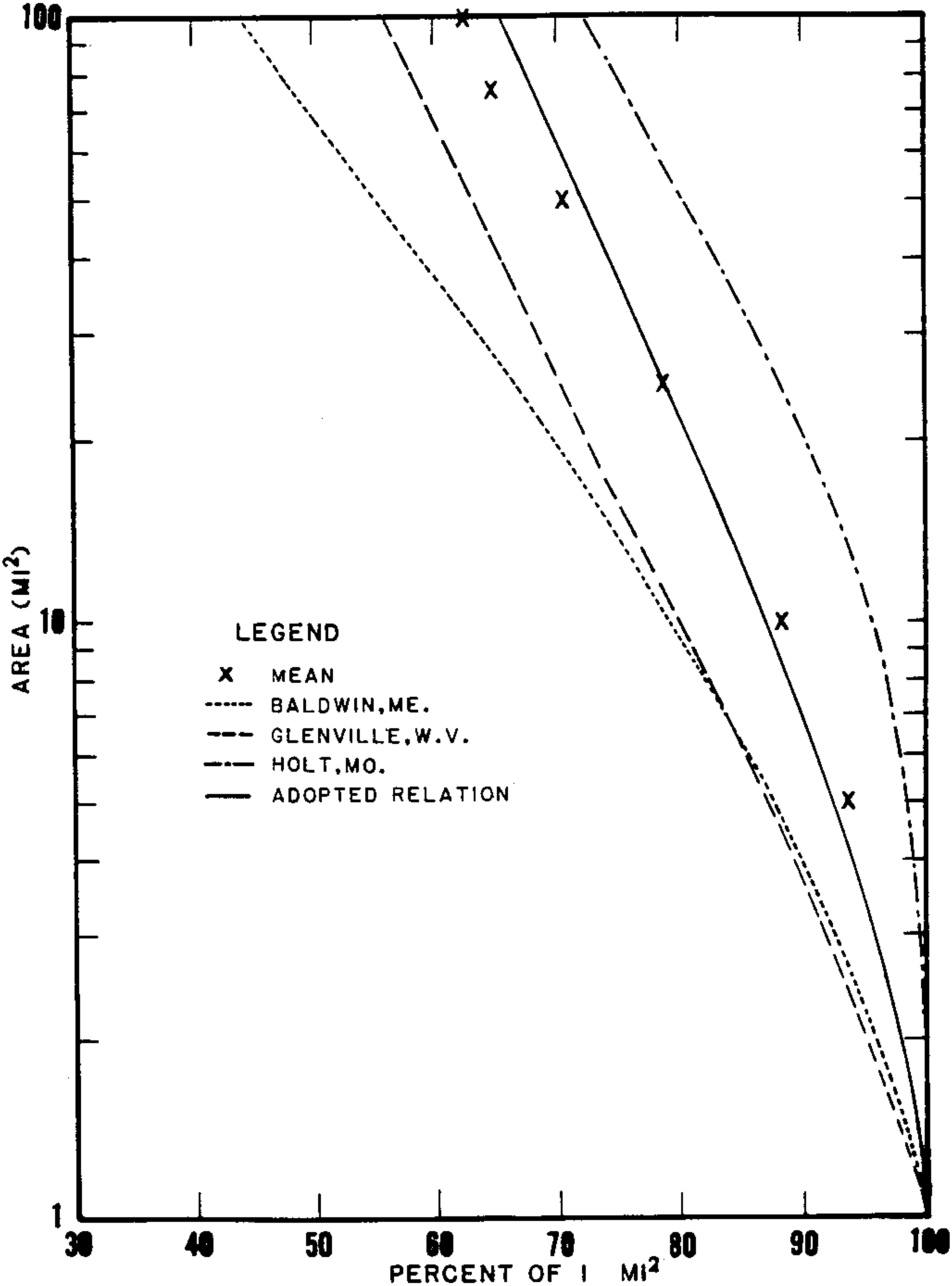


Figure 27.--Depth-area relations for 3 hr with data from other storms.

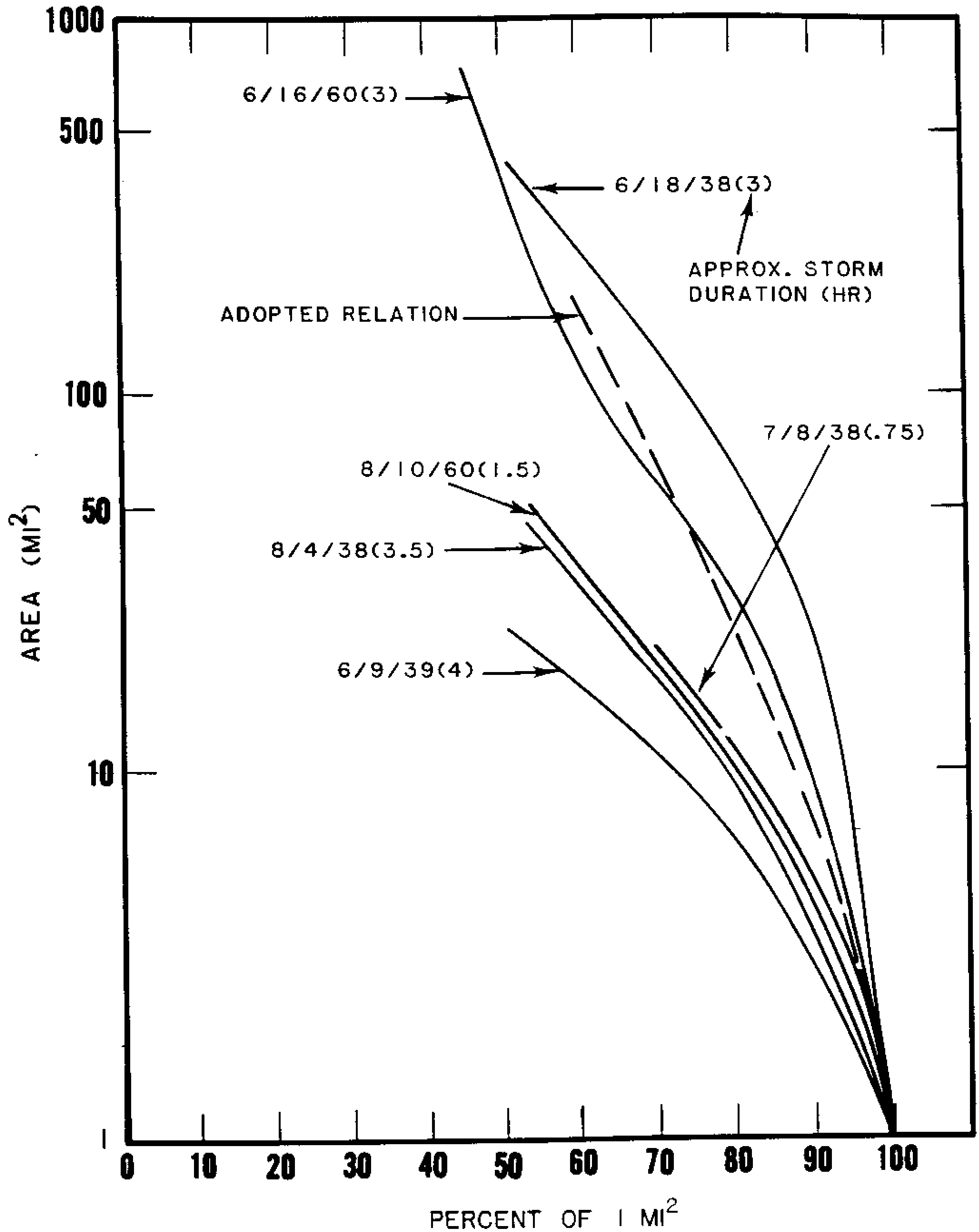


Figure 28.--Adopted 3-hr depth-area curve compared with Tennessee River watershed intense storm data.

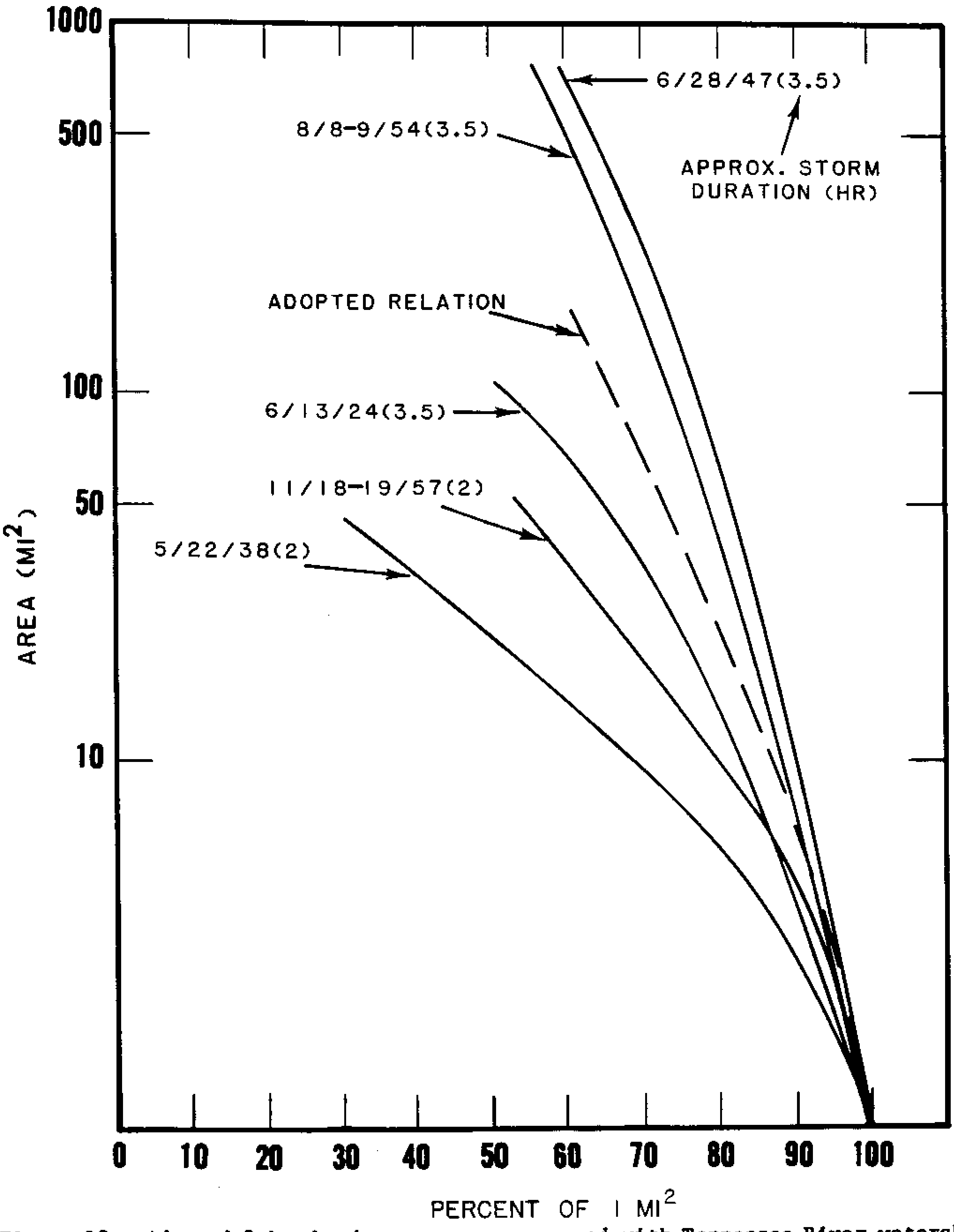


Figure 29.--Adopted 3-hr depth-area curve compared with Tennessee River watershed intense storm data.

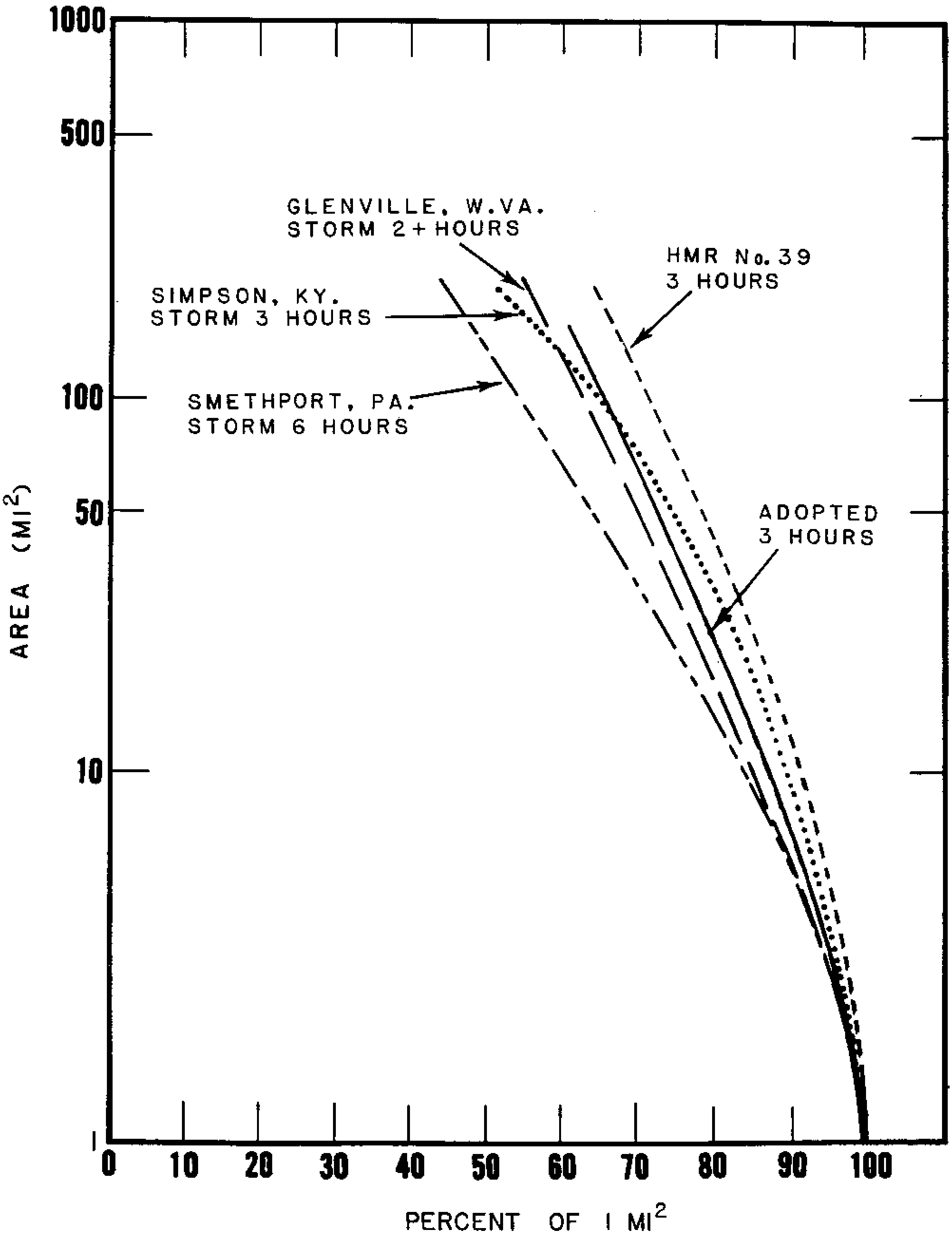


Figure 30.--Adopted 3-hr depth-area curve compared with data from storms outside the basin.

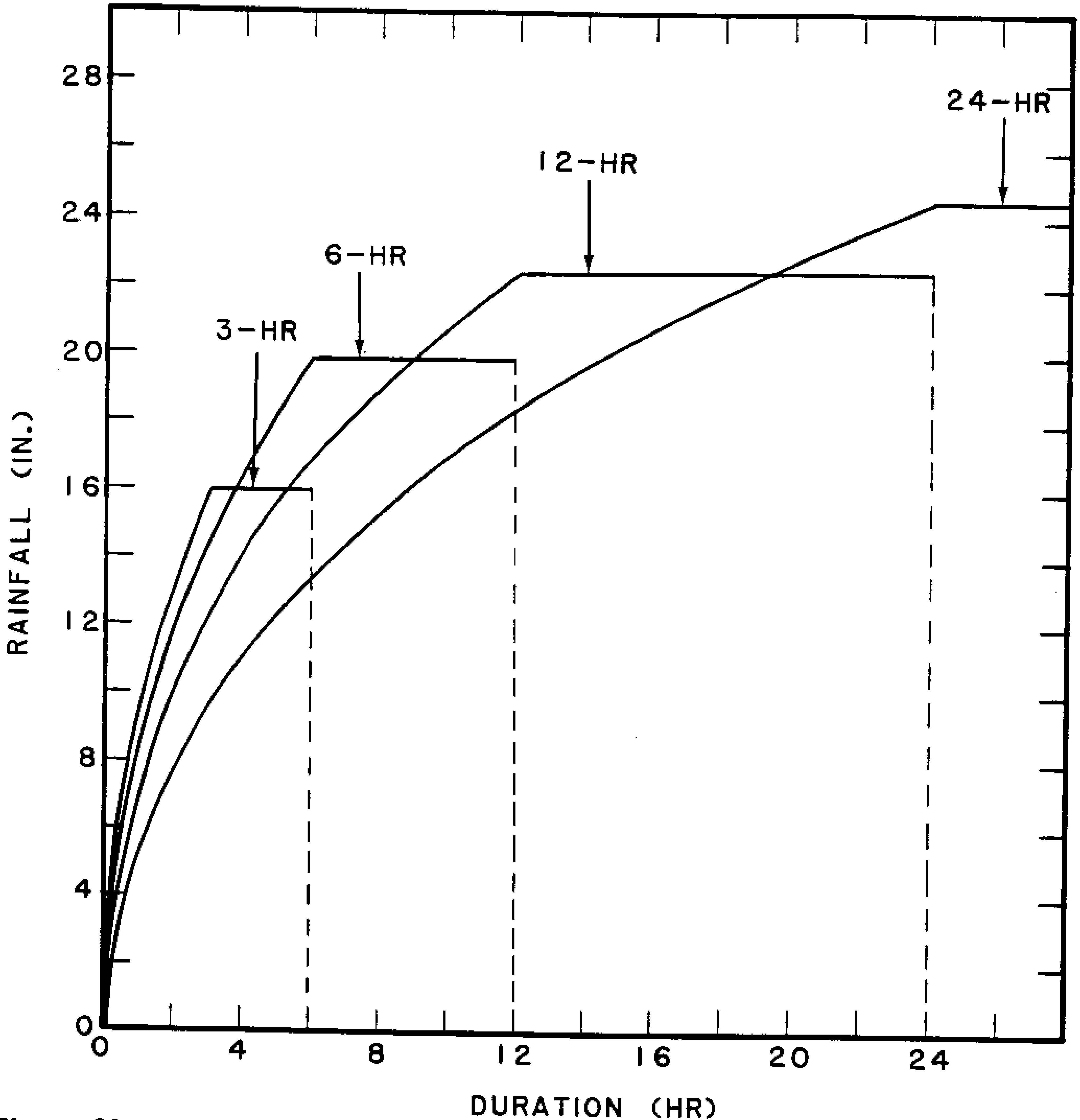


Figure 31.--Adopted depth-duration curves for 3-, 6-, 12- and 24-hr TVA storm ("intermediate" classification).

The appropriate TVA precipitation depth-duration curve for a particular basin is the one that leads to most critical discharge as determined by hydrologic trial. The short-duration curves provide higher peak intensities, whereas the longer duration curves provide larger total volume. It is valid to interpolate between the curves for intermediate storm durations. The curves indicate no rain for 3 hr after the 3-hr storm, no rain for 6 hr after the 6-hr storm, etc. Depth-duration values are undefined beyond the indicated durations. Figures 32 to 34 repeat the depth-duration curves with some of the supporting data from storms listed in table 5.

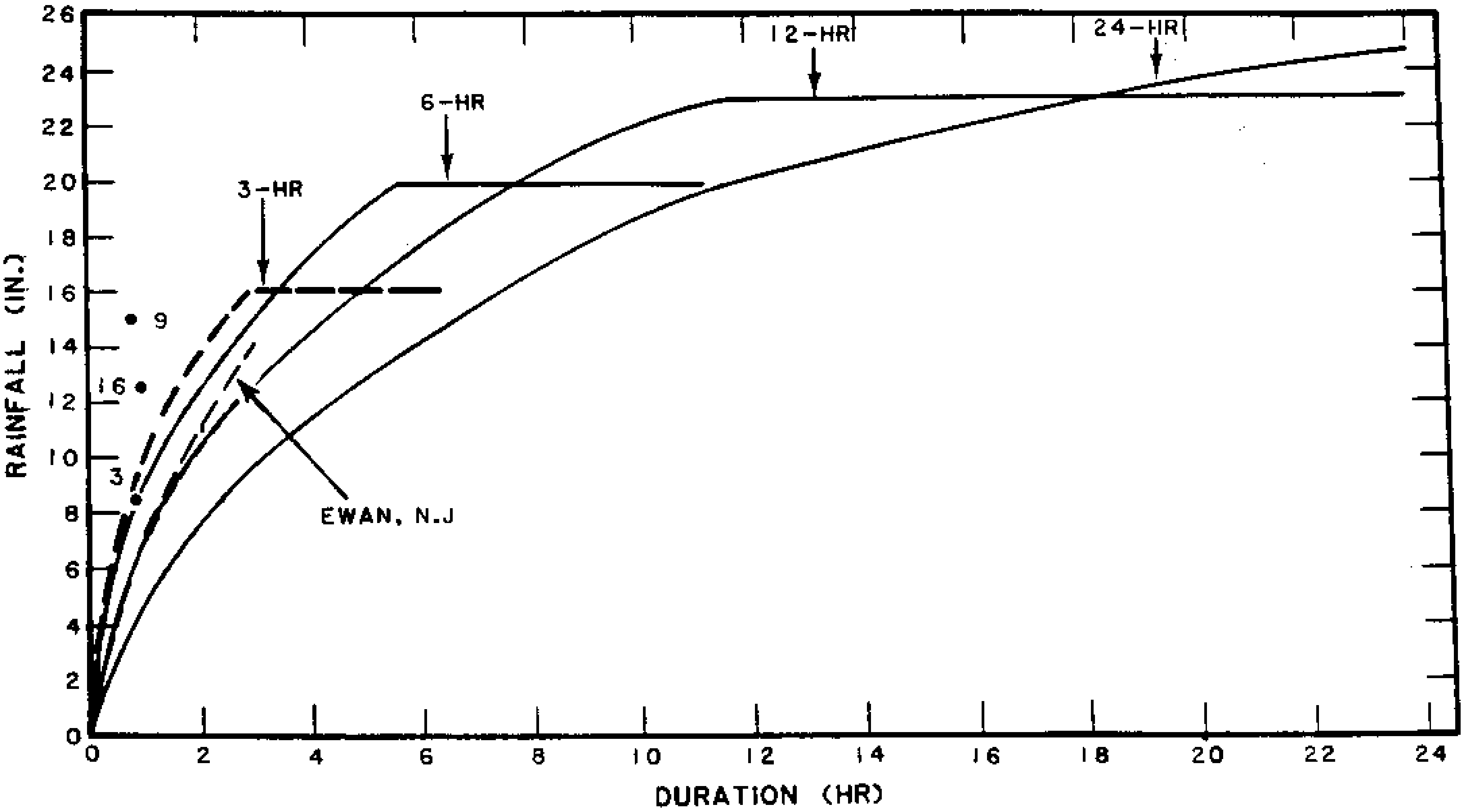


Figure 32.--Curves of figure 31 with supporting data for 3 hr.

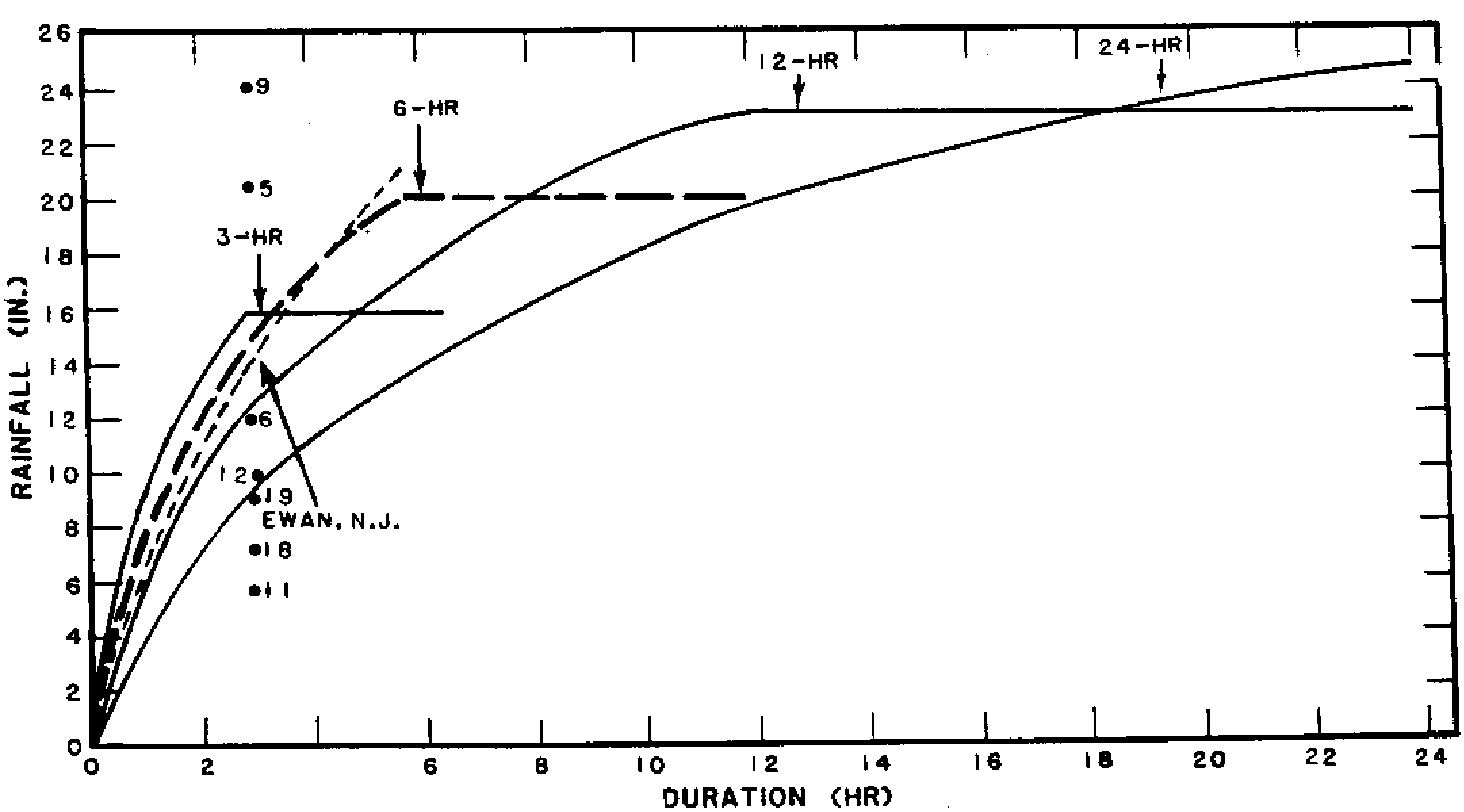


Figure 33.--Curves of figure 31 with supporting data for 6 hr.

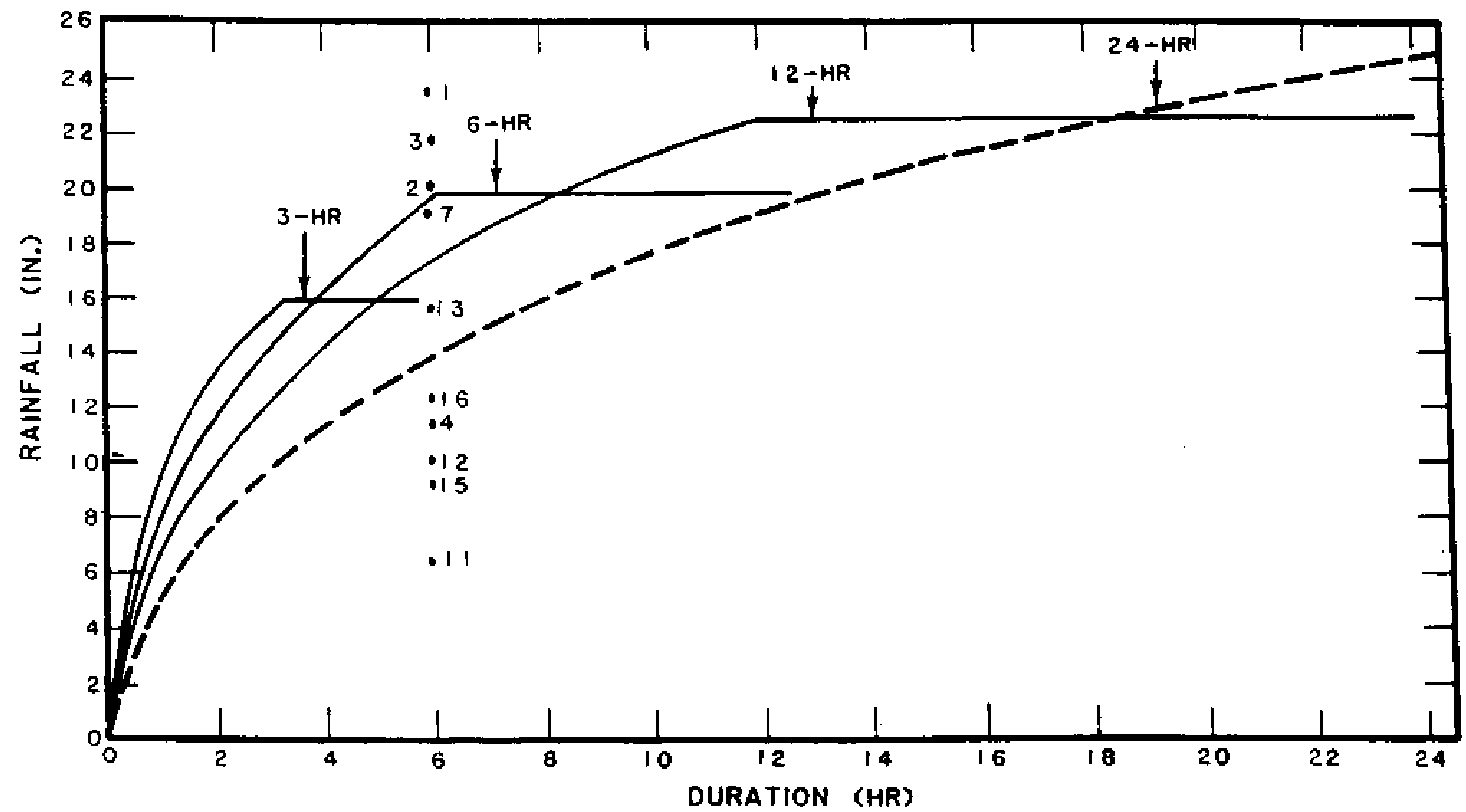


Figure 34.--Curves of figure 31 with supporting data for 24 hr.

The numbers in figure 32 to 34 represent those storms from table 5. Only those storms with appropriate storm data were plotted in figures 32 to 34. For example, if a particular storm had 1- and 3-hr data, then the 1- to 3-hr ratio could be computed; consequently this ratio was multiplied by the TVA 3-hr "intermediate" value in order to obtain the 1-hr value plotted in figure 32. The storm data for the other storms were plotted similarly.

A comparison of extreme 1-hr and 24-hr rain occurrences demonstrates the reasonableness of not specifying that a single enveloping depth-duration relation be used in TVA precipitation application. A summary of annual maximum 1-hr and 24-hr rains at Tennessee Basin stations is shown in figures 35 and 36, which show that the probability of the maximum 1-hr and the maximum 24-hr rains coming from the same storm is small. Such an occurrence is, therefore, appropriately assigned only to the rare PMP event, while a variable set of depth-duration criteria is suitable for the TVA precipitation event.

2.2.12 TVA Precipitation Depth-Duration Relations, Index Value Other Than 19.8 in.

As indicated previously in Figures 15 and 16, beyond the most intense portion of the storm both the PMP and TVA precipitation become increasingly topographically dependent. This is shown by the separation of the "smooth" and "rough" curves in figures 15 and 16. This variation requires that the TVA precipitation depth-duration relation be not only a function of storm duration, as discussed in preceding paragraphs, but also a function of index value (fig. 24 and 25). The requisite set of depth-duration curves, derived by interpolations from figures 15 and 31 are found in figures 37 to 40.

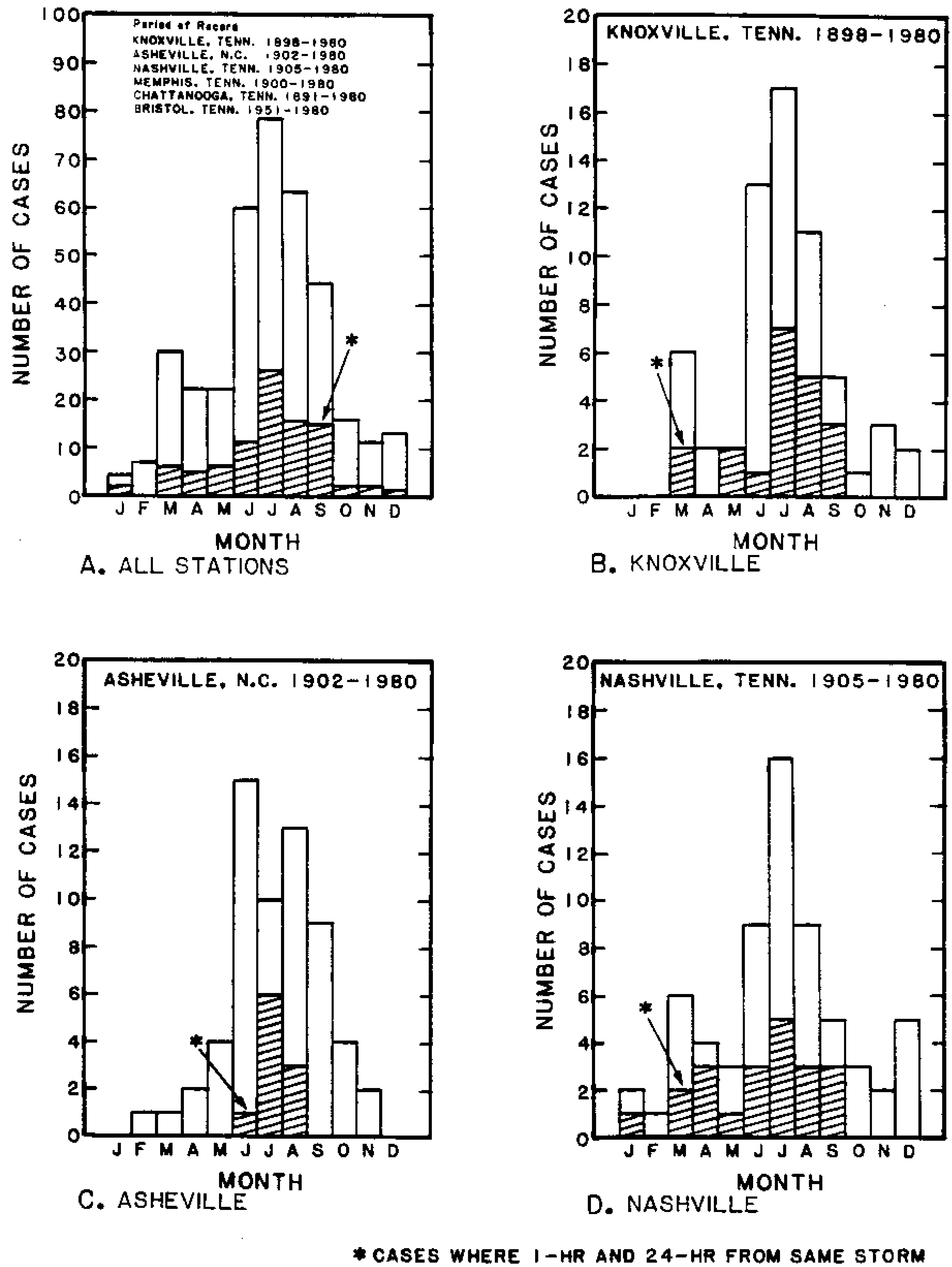


Figure 35.--Frequency distribution of annual maximum 1-hr rains (open) and joint occurrence of 1- and 24-hr rains in the same storm (A, all stations, B, Knoxville, C, Asheville, and D, Nashville).

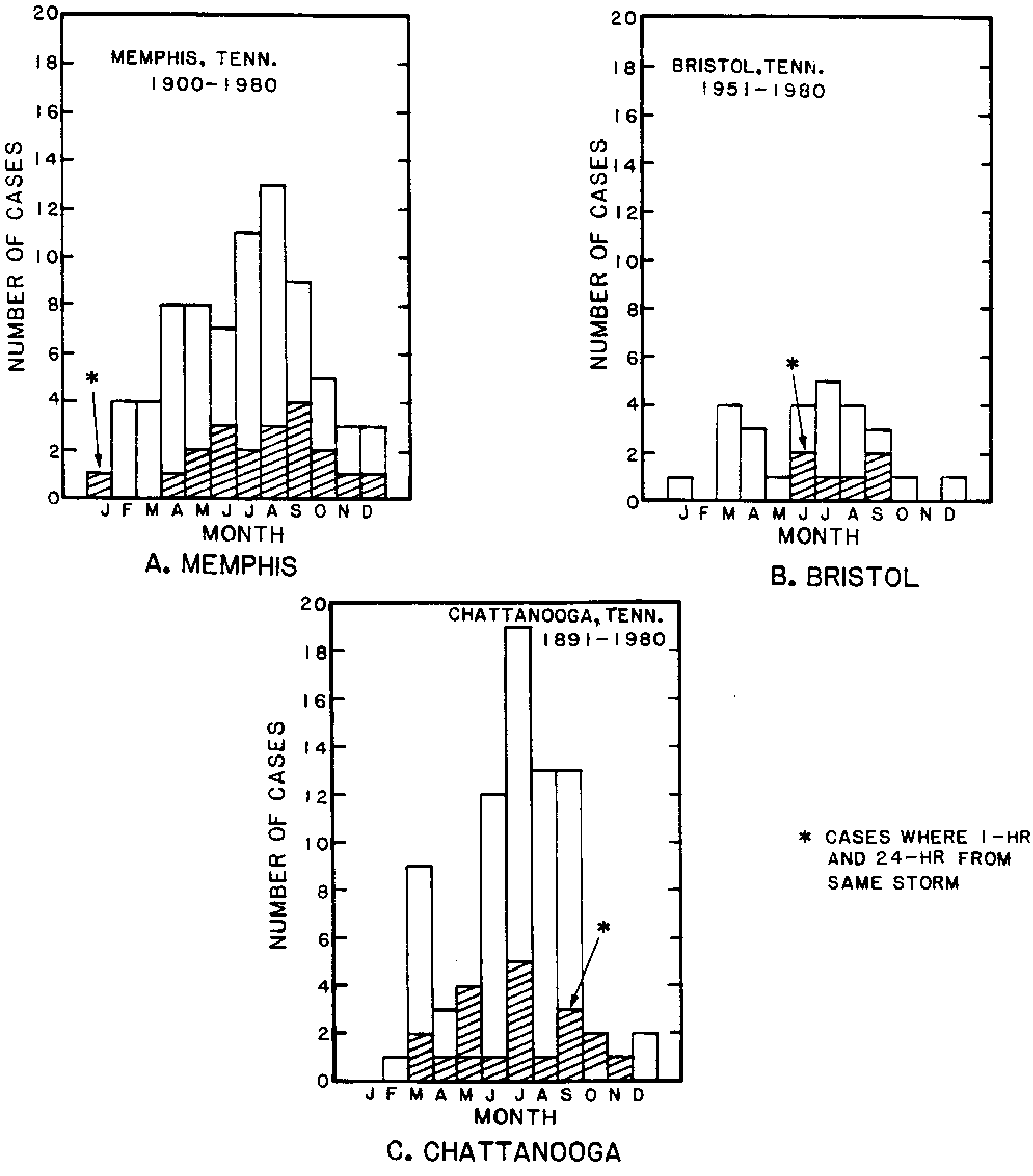


Figure 36.--Frequency distribution of annual maximum 1-hr rains (open) and joint occurrence of 1- and 24-hr rains in the same storm (A, Memphis, B, Bristol, and C, Chattanooga).

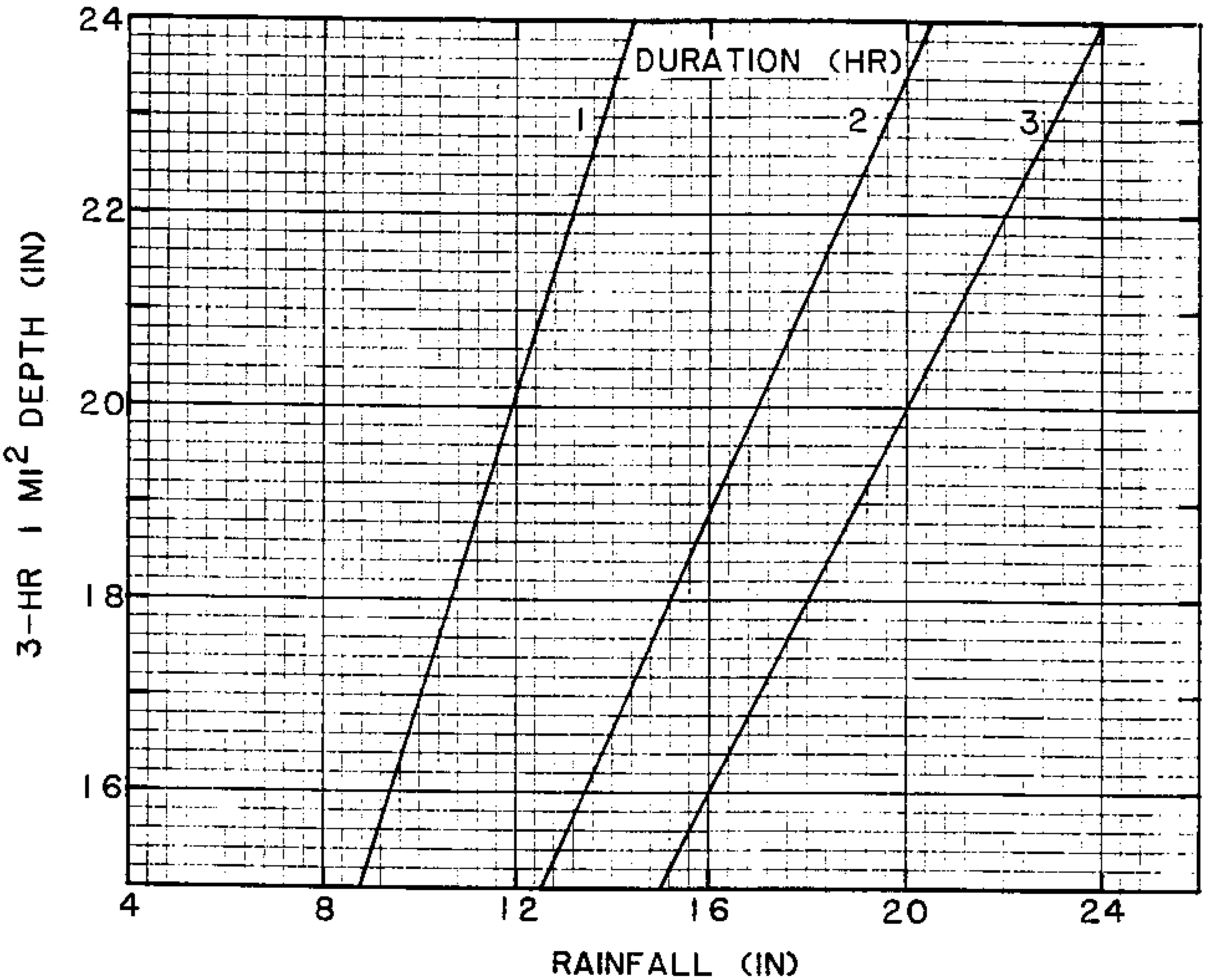


Figure 37.--Depth-duration relations for 3-hr TVA precipitation storm.

2.2.13 Depth-Duration Criteria for PMP

To obtain the durational distribution of the probable maximum precipitation for various index values (fig. 22 and 23), a procedure is followed allowing greater increases than for the TVA storm. Rainfall during the one time period does not necessarily preclude rain during a succeeding period. Following the procedure of HMR No. 33 (Riedel et al. 1956) and HMR No. 51, (Schreiner and Riedel 1978) a PMP storm is subdivided into durational increments in accordance with the enveloping depth-duration curve, such as figure 16 (sect. 2.2.7.1). For example, the 3-hr PMP is followed in the next 3 hr by the difference between 6-hr PMP and 3-hr PMP. The PMP depth-duration nomogram is shown in figure 41.

2.2.14 Temporal Distribution of Rainfall

Previous sections have dealt with magnitudes of temporal increments of TVA and PMP storms. This section specifies the arrangement of these increments into a sequence.

Extreme storms in Tennessee have generally been one-burst affairs in which little or insignificant rain follows the extreme 3-hr rainfall. Storm experience, in general, points to the occurrence of a 24-hr rainfall in a single burst. With this in mind, the following guidelines are suggested for the temporal distribution of the PMP and TVA rainfall.

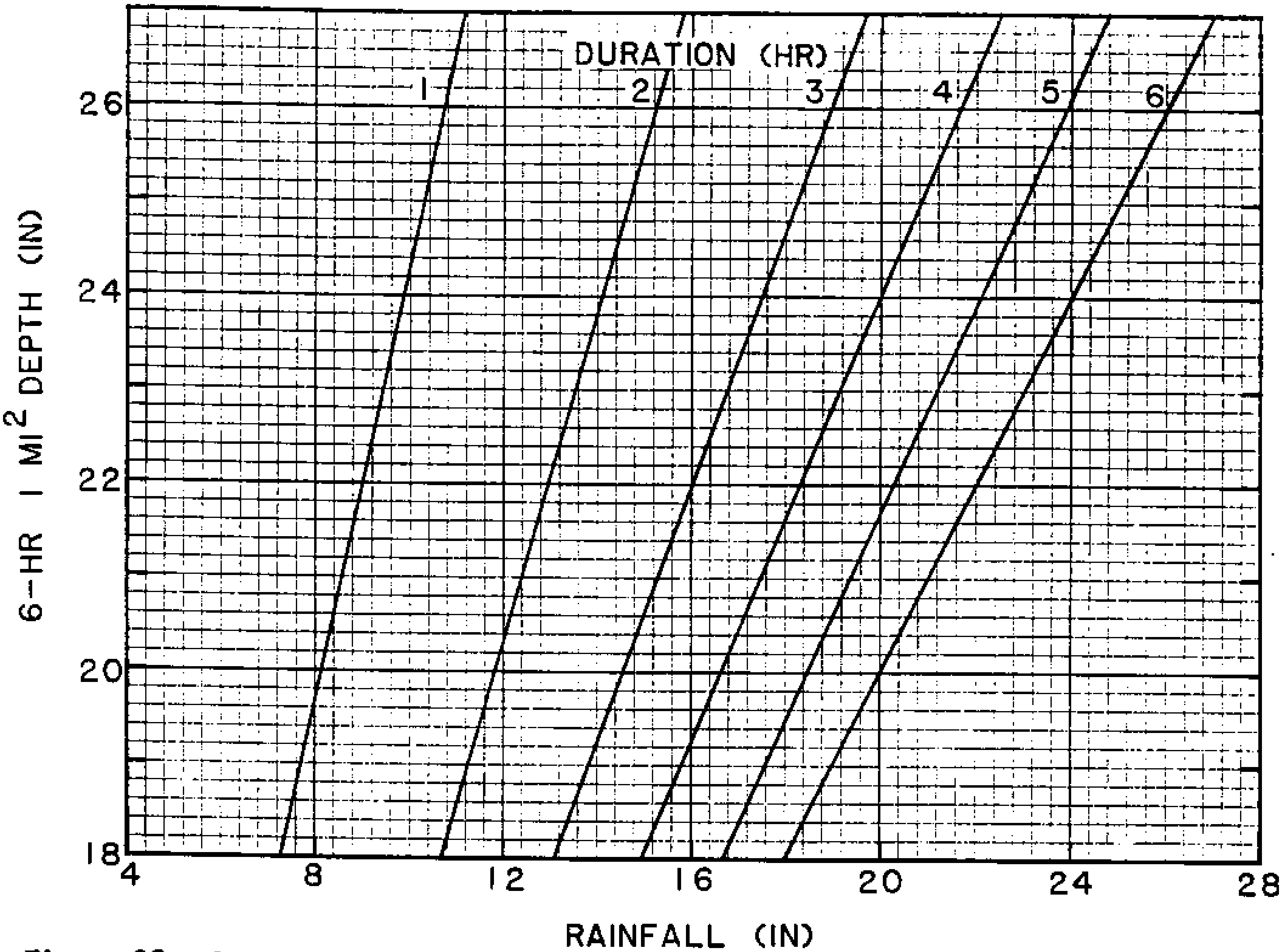


Figure 38.--Depth-duration relations for 6-hr TVA precipitation storm.

2.2.14.1 6-hr Rainfall Increments in 24-hr Storm. Arrange the four 6-hr increments such that the second highest increment is next to the highest, the third highest increment adjacent to these, and the fourth highest increment at either end. This still allows various arrangements, and the critical one is that which would yield the most critical hydrograph.

2.2.14.2 1-hr Increments in Maximum 6-hr Rainfall. Any arrangement of 1-hr increments is acceptable as long as the two highest hourly amounts are adjacent, the three highest hourly amounts are adjacent, etc.

2.3 Summary

In this chapter, development of the PMP and TVA precipitation storm type appropriate to the Tennessee River watershed small basin ($\leq$100 mi^2) was described. It was concluded that a thunderstorm is the most appropriate PMP-type storm in the Tennessee River watershed. This type of storm usually occurs between April and September, but the months of July and August are taken to be the months of small-basin PMP and TVA precipitation.

PMP depth-duration relationships through 6 hr were derived for small basins using the Smethport, PA and Holt, MO storms as anchor points for the "rough" and "smooth" terrain categories, respectively. To extend the depth-duration curves to 24 hr, data from appropriate PMP-type storms outside the Tennessee River

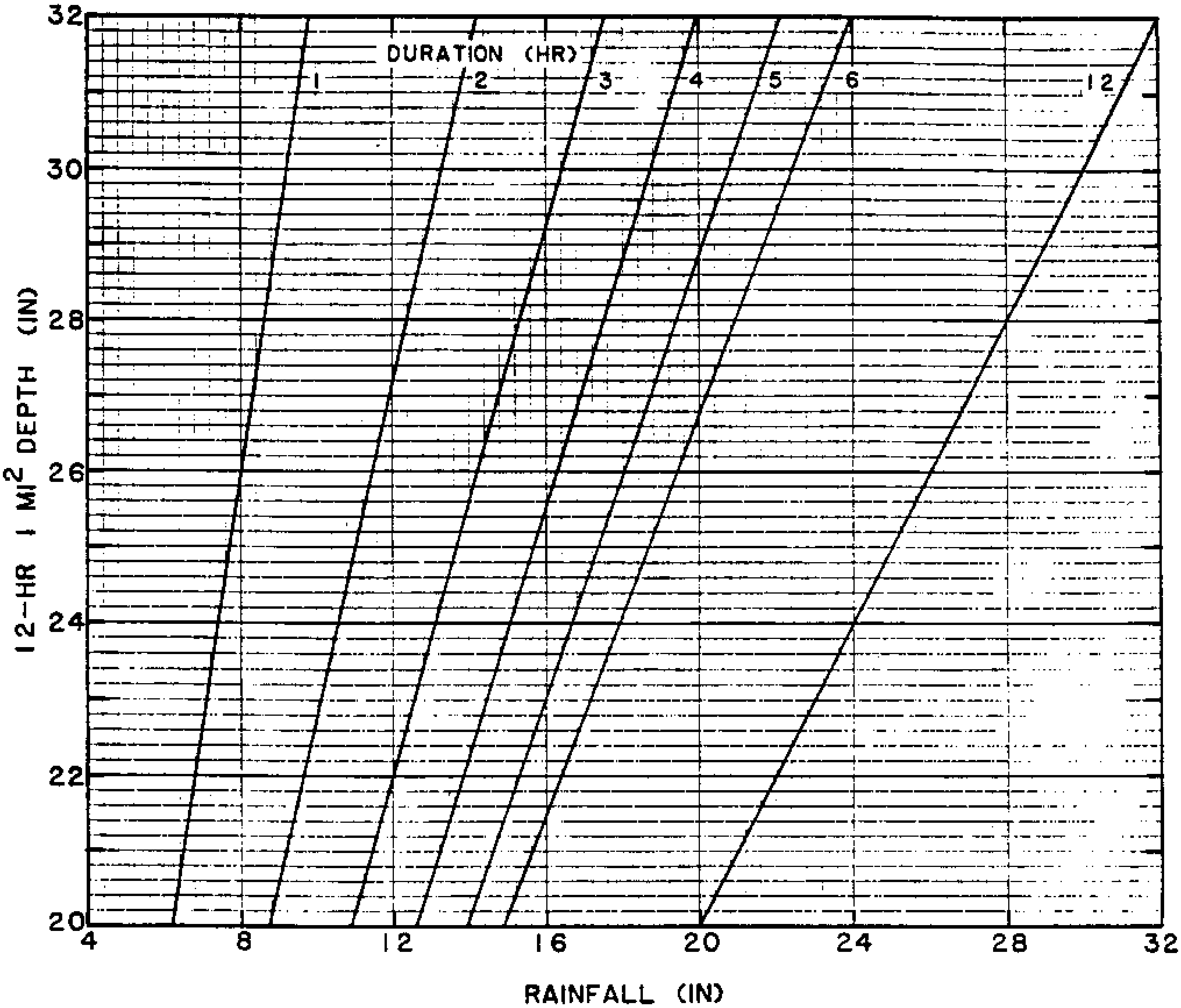


Figure 39.--Depth-duration relations for 12-hr TVA precipitation storm.

watershed were plotted at durations of 12, 18, and 24 hr and a curve of "best fit" was constructed. The adopted relations from 6 to 24 hr were applied to both the "rough" and "smooth" PMP categories.

In addition, using storms that have occurred within the Tennessee River watershed, depth-duration relations out to 24 hr for "rough-," "intermediate-," and "smooth-" terrain categories were derived for a lesser precipitation called TVA precipitation. Because the probability of a maximum 1-, 3-, 6-, or 24-hr maximum rain occurring within, coming from the same storm over any Tennessee River watershed is small, a variable set of depth-duration criteria was adapted for TVA precipitation.

Finally, depth-area and depth-duration nomograms were developed for the PMP and TVA precipitation which permit the user to obtain PMP and TVA precipitation estimates for durations of 1 to 24 hr and basin sizes of 1 to 100 mi^2.

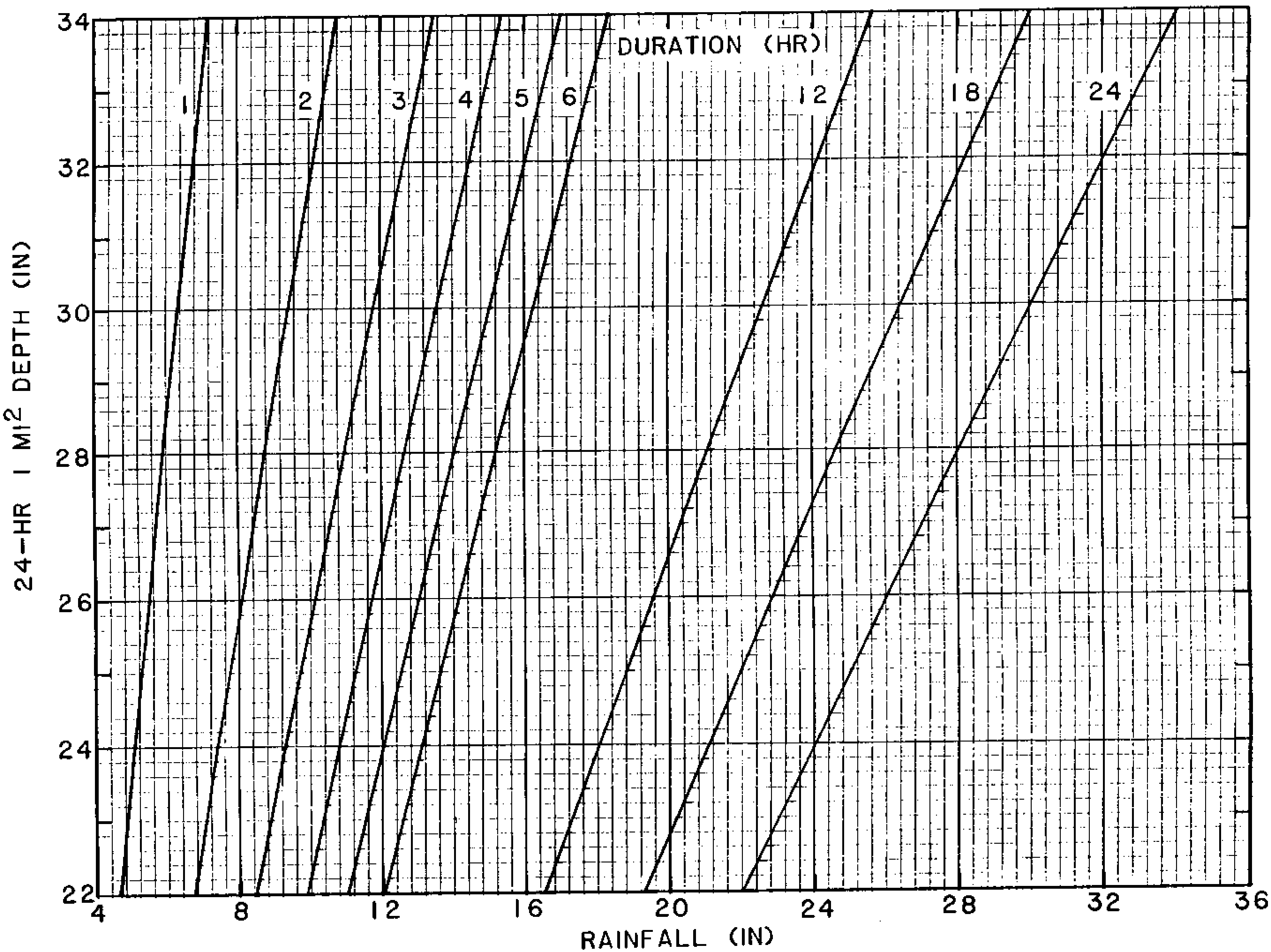


Figure 40.--Depth-duration relations for 24-hr TVA precipitation storm.

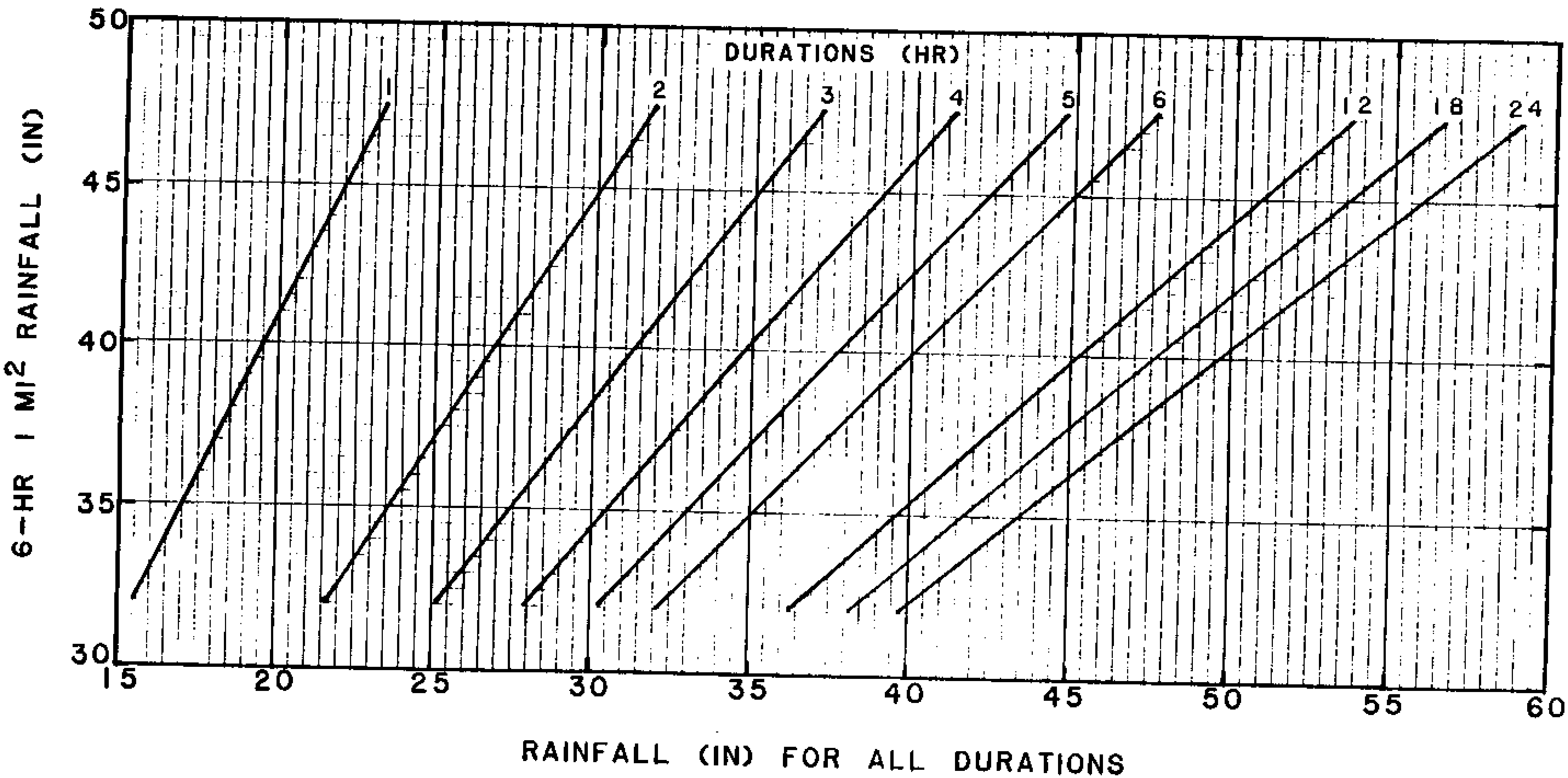


Figure 41.—Depth-duration nomogram for 24-hr PMP storm.

3. PMP AND TVA PRECIPITATION FOR 100 TO 3,000-MI^2 BASINS

3.1 Introduction

Chapter 2 provided a means of obtaining estimates of PMP and TVA precipitation for basins up to 100 mi^2 in area. In this chapter, a generalized description of the development used to obtain such estimates for drainages from 100 to 3,000 mi^2 in area is presented.

This chapter is divided into three sections. The first section describes meteorological characteristics of pertinent storms. The second section discusses the derivation of a generalized methodology used to obtain PMP and TVA precipitation estimates. Finally, the third section discusses solutions to the problem of differences that may arise in estimating PMP at the 100-mi^2 interface using the small and large basin procedures.

Because the eastern portion of the basin is more mountainous than the western portion and therefore exerts a more complicated control on precipitation, the procedures for obtaining generalized estimates differ between the mountainous east and the remainder of the Tennessee Valley region.

3.2 Storm Characteristics

3.2.1 Introduction

In chapter 2 of this report the PMP type warm-season small-area thunderstorm situation was described. In HMR No. 41 the winter-type PMP storm for basins of 8,000 mi^2 and larger was the main concern. Here we are concerned with the type or types of situations that will produce PMP and TVA precipitation values over intermediate-size basins between 100 and 3,000 mi^2.

A variety of specific rain-producing mechanisms may be involved in the PMP or TVA precipitation over a 3-day period. A decadent tropical storm or hurricane may or may not be involved. Relevant storms are discussed in the following sections.

3.2.2 Summer Control of Maximum United States Rainfall

Maximum observed rainfall near the Gulf Coast occurs in summer for areas up to at least 2,000 mi^2. The maximum observed values from "Storm Rainfall" (U.S. Army 1945-) are listed in table 8. All table 8 values, except those for 6 hr, are from the Yankeetown, FL, hurricane "Easy" storm of September 3-7, 1950. The 6-hr values are from the Thrall, TX storm of September 8-10, 1921.

A hurricane like the Altapass, NC Storm of July 1916, may best typify the PMP storm for the mountainous eastern portion of the Tennessee watershed. The remaining two-thirds of the Tennessee watershed may also be influenced by decadent tropical storms or hurricanes (Neumann et al. 1978). Figures 42 and 43, reproduced from HMR No. 41 (Schwarz 1965) (fig. 3-20 and 3-21), show some typical tracks of past tropical storms. However, the distance of the Tennessee watershed from the ocean source increases the chance that a more complex weather situation than a decadent tropical storm alone is the cause of the 3-day PMP or TVA precipitation. The record-breaking rains in the Tennessee Basin mountains in late September and early October 1964 were produced by a storm which will be used to demonstrate this point.

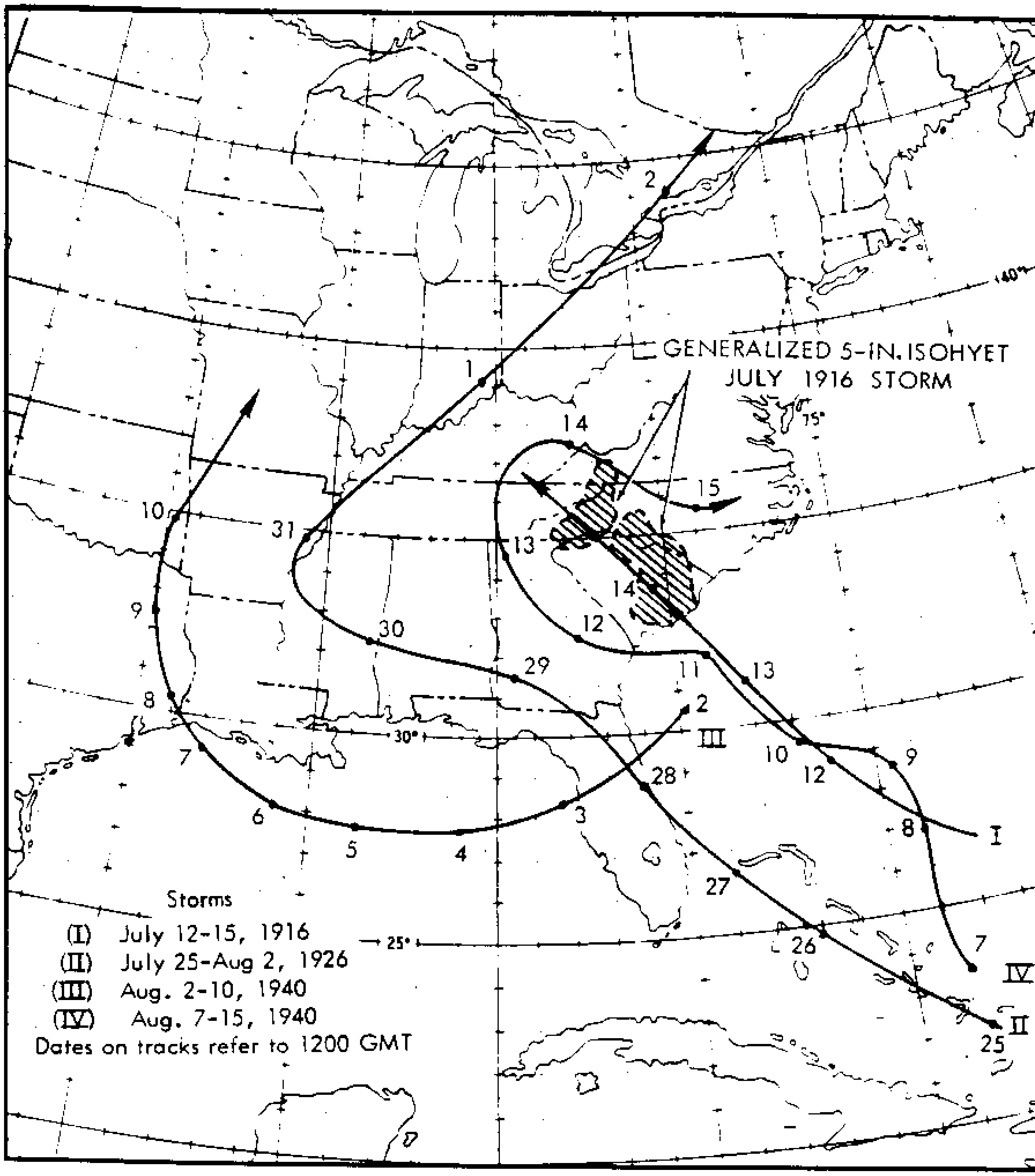


Figure 42.—Hurricane tracks from the Atlantic Ocean.

Table 8. Maximum observed United States rainfall (in.)

Area (mi^2)	Duration (hr) 6	12	18	24	36	48	72
200	17.9	25.6	31.4	34.2	36.7	37.7	39.2
500	15.4	24.6	29.7	32.7	35.0	36.0	37.3
1000	13.4	22.6	27.4	30.2	32.9	33.7	34.9
2000	11.2	17.7	22.5	24.8	27.3	28.4	29.7

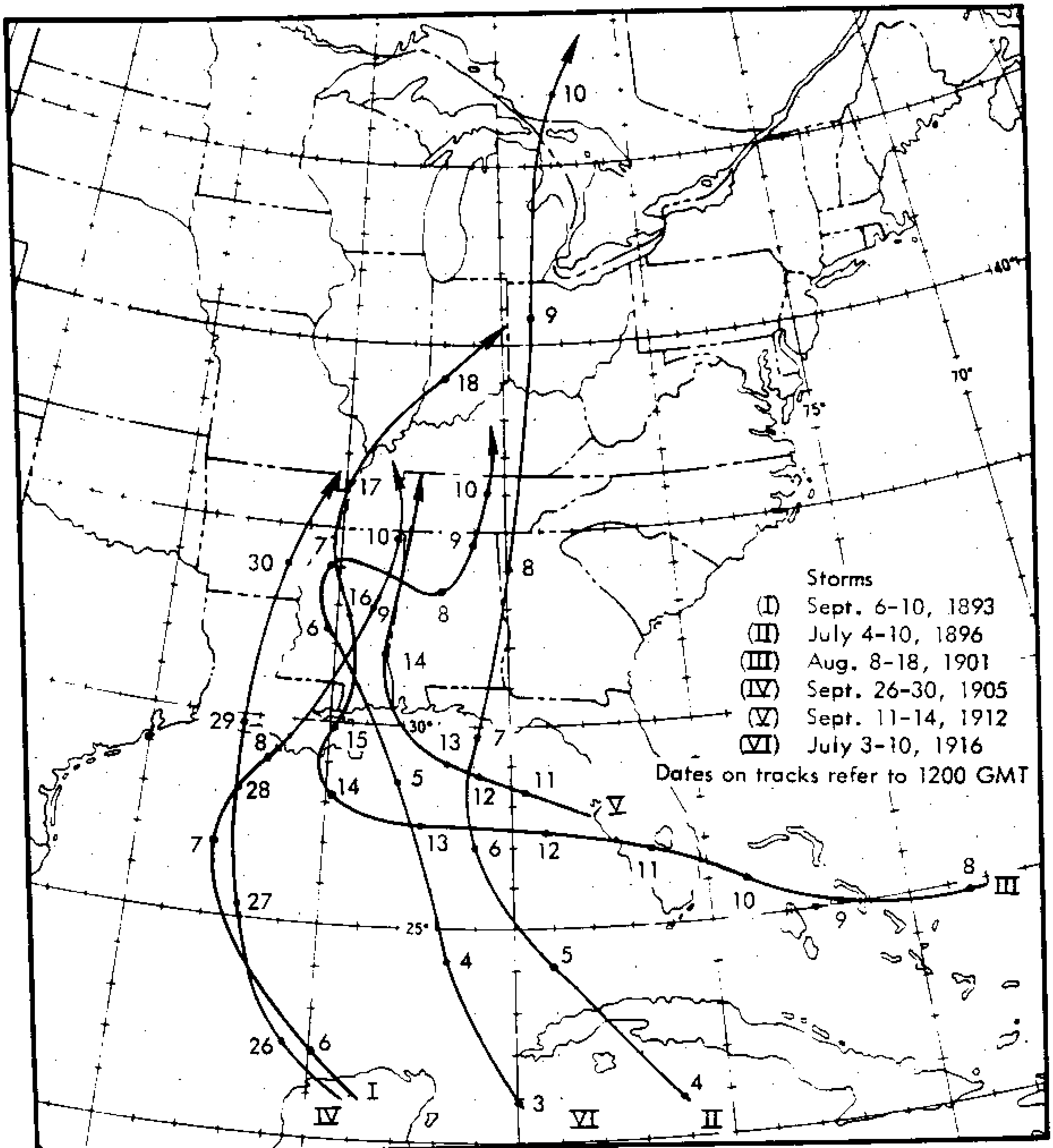


Figure 43.--Hurricane tracks from a southerly direction.

3.2.3 September 28-October 4, 1964 Storm Period

This "storm" affected the mountainous eastern portion of the Tennessee River basin and demonstrates a combination of types that gave heavy total precipitation over 6 days. Separate types of events produced about equally heavy 24-hr rains at the same location within this storm period. The first of the two storms dumped its rain on September 28-29, while the remnants of hurricane Hilda added more rain on October 4-5. Figures 44 through 49 are presented to help clarify the narrative discussion.

The TVA has published a fairly comprehensive account of the floods of September and October 1964 (TVA 1965). A few of the highlights of the associated storm events as listed at the beginning of the TVA report are summarized here:

1. The most significant rain was "...along the crest of the Blue Ridge in western North Carolina and northern Georgia."

2. Rosman, NC established new rainfall records with a total accumulation from September 28-October 4, of 35.4 in.

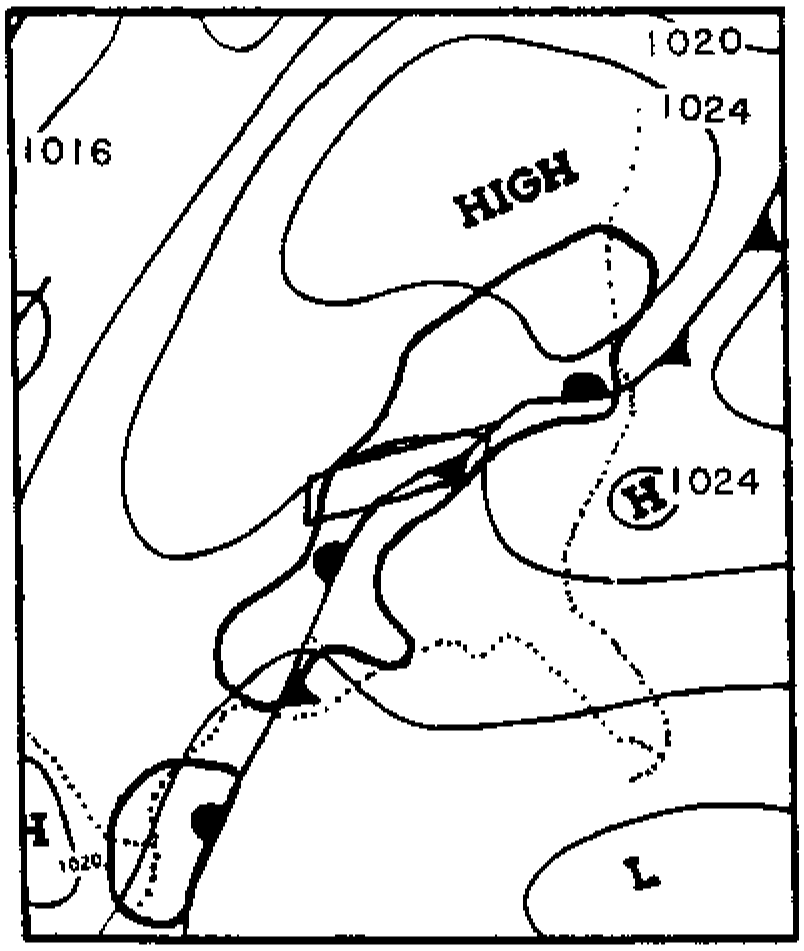
3. In the second half of the storm period, "...floods in the upper French Broad River basin were the highest since 1916 on most streams." Also, "On the upper Little Tennessee river the flood exceeded the highest previously known flood...."

A high volume of nonorographic rainfall was made possible in the September 28-29 storm by a large low-level transport of moisture into an area of low-level convergence associated with an inverted-V trough and a quasi-stationary front. This type is a classic producer of heavy rain throughout the central United States. Added to the low-level convergence mechanism in this storm was an orographic upslope influence as evidenced by the primary rain center near Rosman, NC.

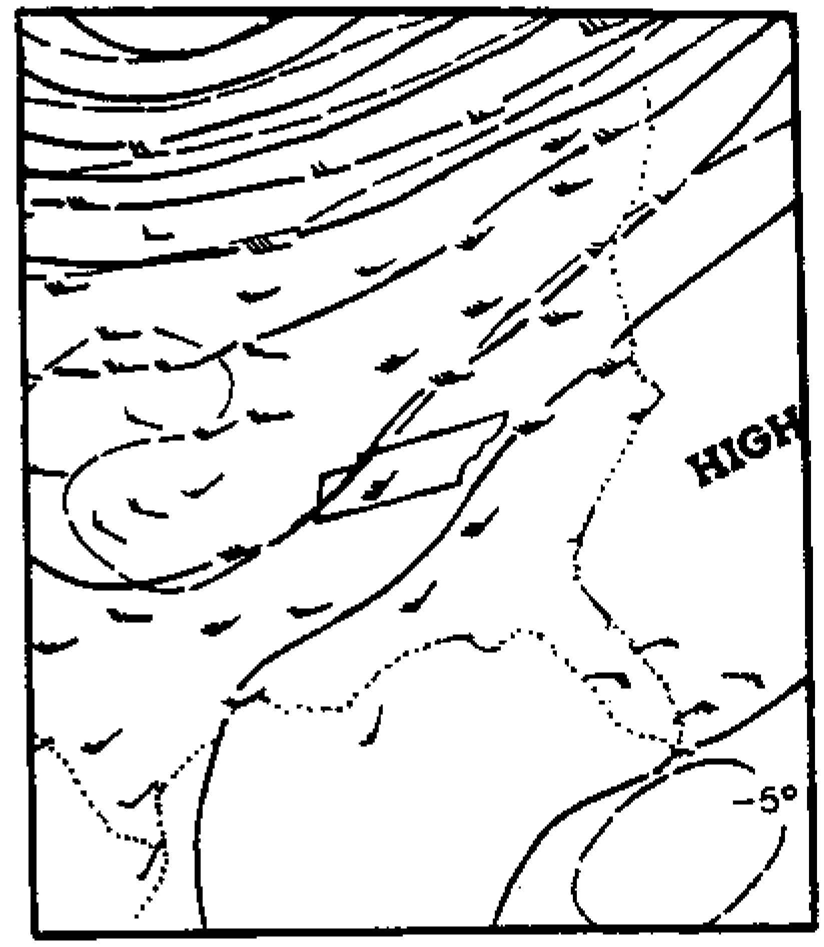
The 500 mb charts (figs. 44 and 45) show a trough in the westerlies which did not extend its influence to the vicinity of the hurricane. This synoptic picture permitted the hurricane to continue at a rather slow rate. Had a major trough entered the area the hurricane would have likely turned to a northeasterly course and increased its speed so that the rain would not have fallen over the same area as the observed heavy rain. Such a "fixing" of the broadscale synoptic features is extremely important for heavy rains to repeat over approximately the same area. See, for example, the discussion on pages 3-4 of HMR No. 38 (Schwarz 1961).

That the persisting, or geographically fixed, influx of very moist air was an important feature of the repeating heavy rains of September 28-October 4 is demonstrated by figures 48 and 49. Highlighted on figure 48 is the pronounced 850-mb tongue of moisture extending toward the eastern border of Tennessee. Based on the evaluation of the Showalter Index (Showalter 1953), figure 49 shows that the most unstable region was centered from northern Alabama into eastern Tennessee in conjunction with persisting high values of precipitable water. (A Showalter index of zero represents a marked degree of instability since this is an average for the whole storm period.) The precipitable water values in figure 49 are also for the period September 28-October 4, so their magnitude must be judged accordingly. Figure 50 provides a basis for judgment, giving the climatic assessment of precipitable water values for an atmospheric sounding station south of the Tennessee Basin. The 12-hr persisting dew point data in figure 50 are from charts developed in the Hydrometeorological Branch and published in the National Climatic Atlas (Environmental Data Service 1968). Their precipitable water equivalent is based on an assumed saturated atmosphere. The 100-yr values of precipitable water, as well as the maximum precipitable water of record (fig. 50), are derived from twice-a-day precipitable water measurements for Montgomery, AL, for the period 1949-1973.

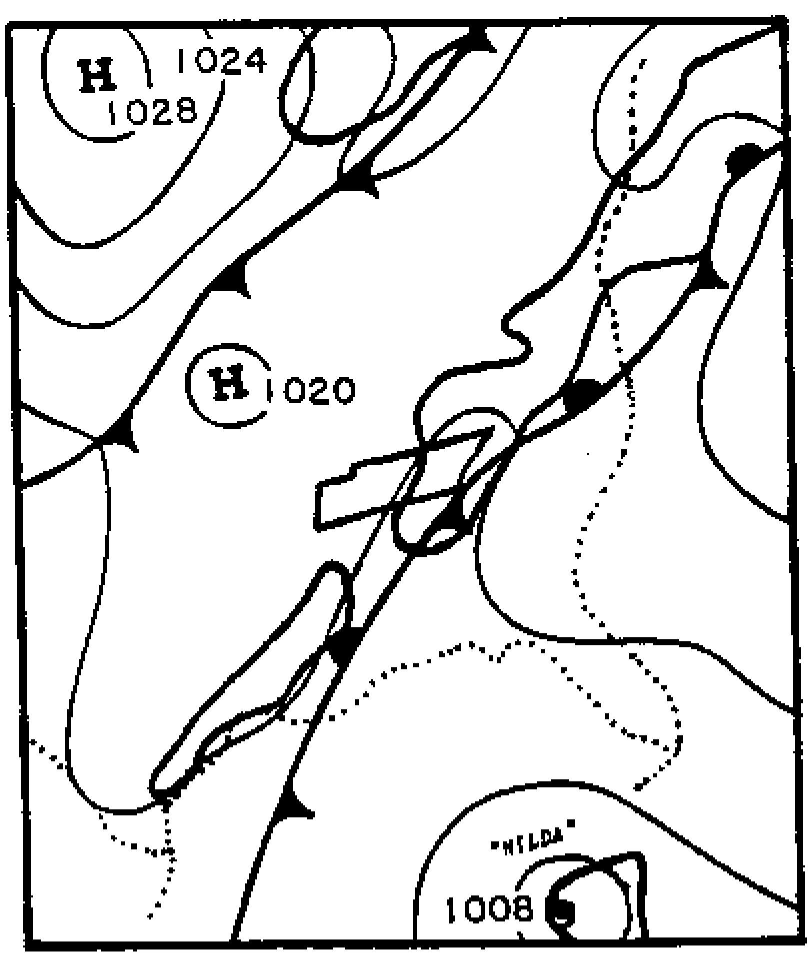
For a portion of the 1964 storm period, surface dew points of 74°F were observed near the Gulf Coast, while on October 2, Burrwood, LA observed a precipitable water value of 2.34 in. (O'Connor 1965).



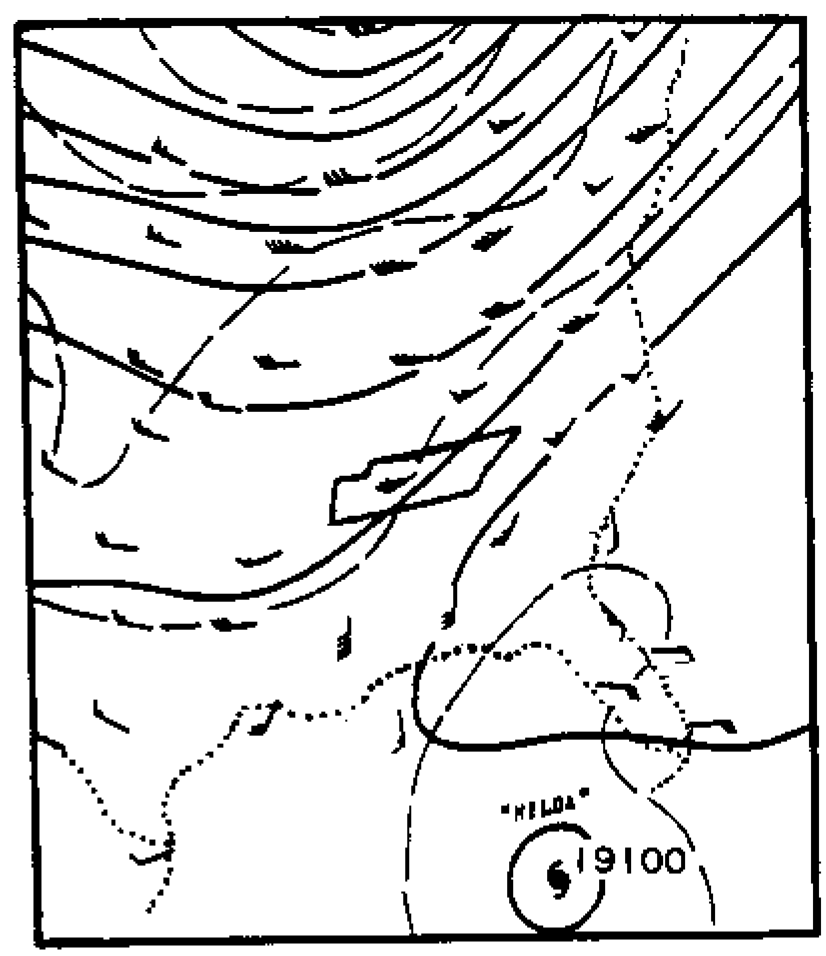
SEPT. 28, 1964 Surface 1800GMT



SEPT. 28, 1964 500mb 0000GMT



SEPT. 29, 1964 Surface 1800GMT

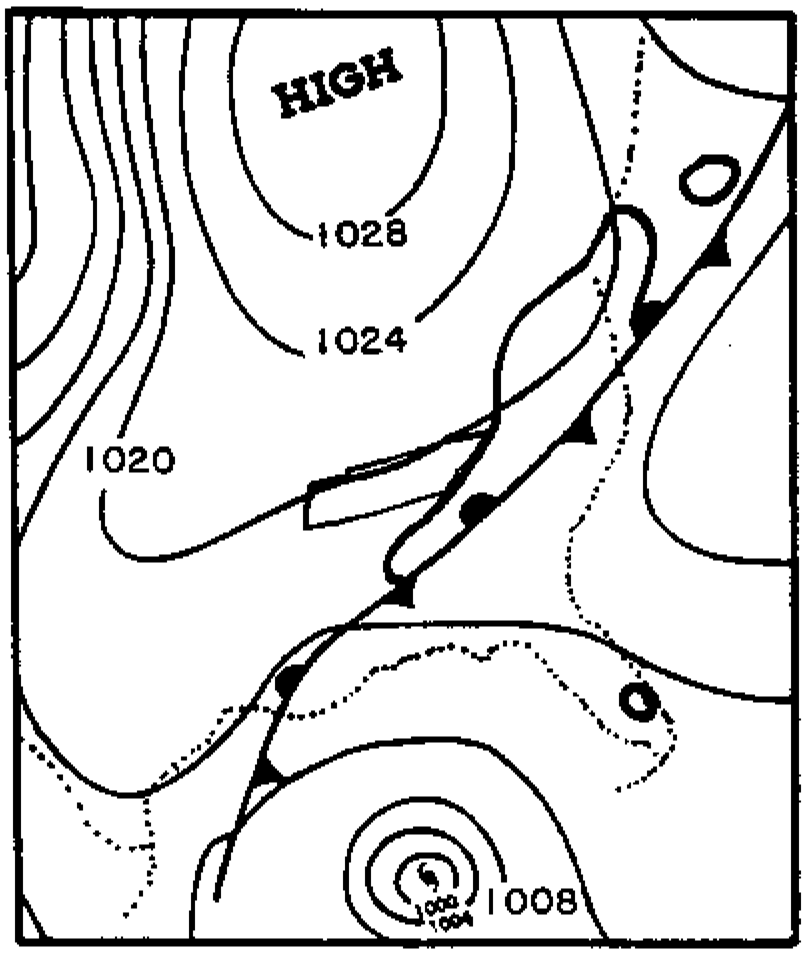


SEPT. 29, 1964 500mb 0000GMT

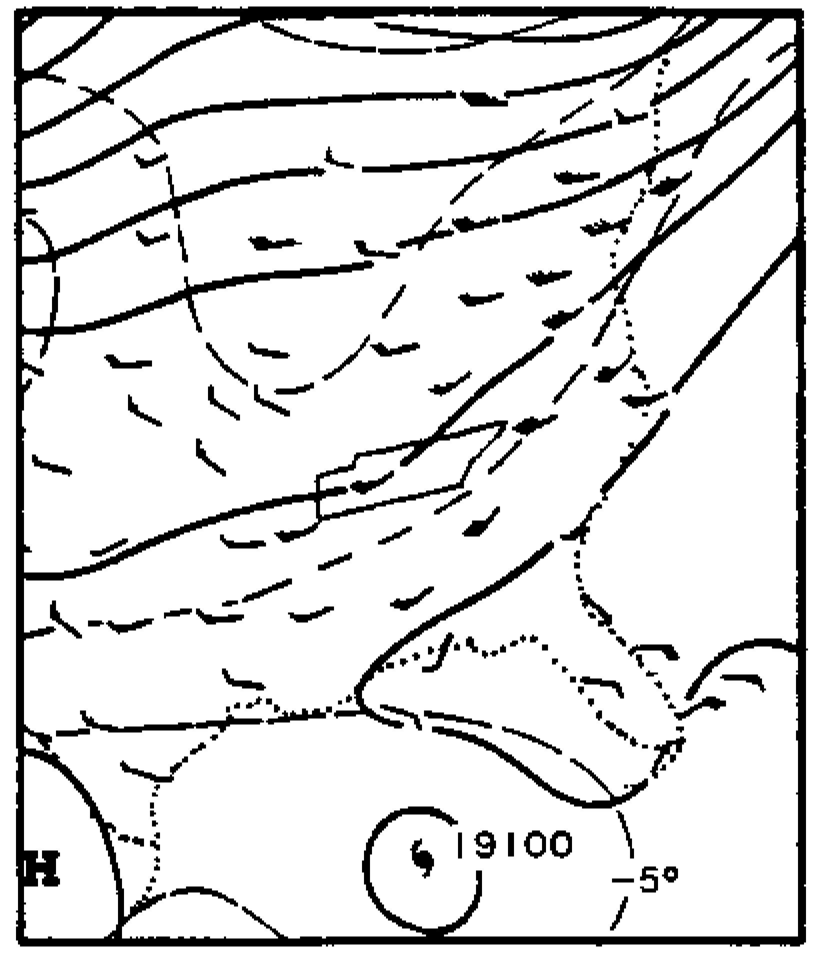
Figure 44.--Surface and upper-air weather maps for September 28-29, 1964.

3.2.4 Season of Large-Area PMP and TVA Precipitation

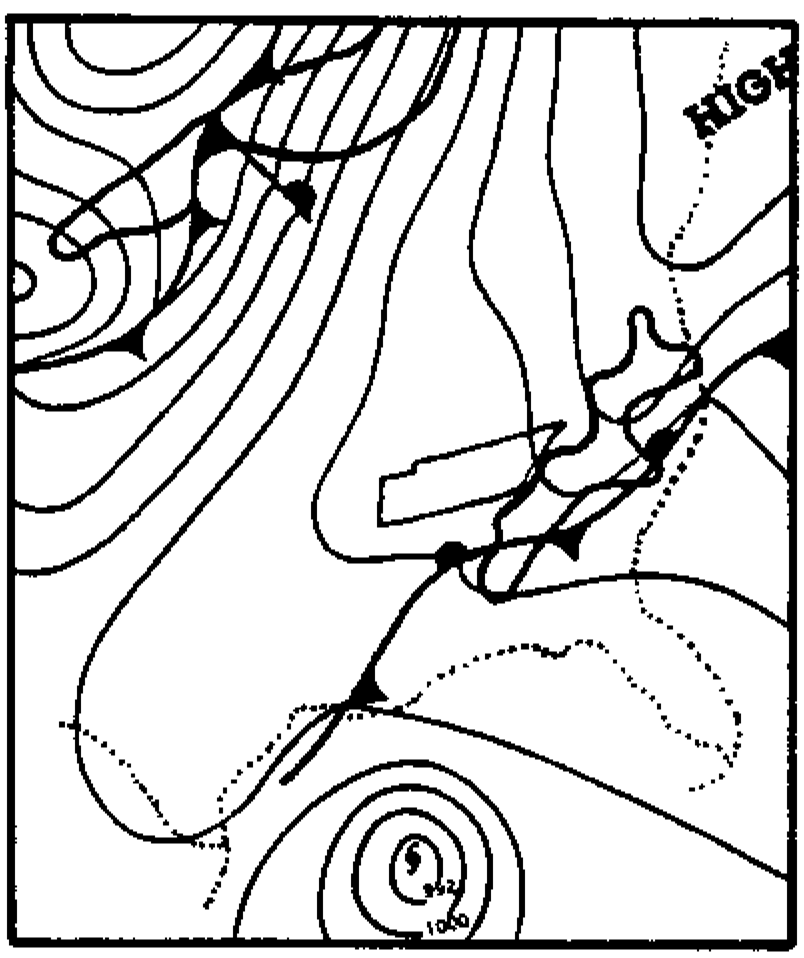
Guidance for assigning the season for the all-season PMP and TVA precipitation determined in this report is taken from the monthly analyses of maximum persisting 12-hr dew point (Environmental Data Service 1968). Sustained high moisture inflow is one of the most important criteria for large area precipitation. The curves in figure 50 are typical of the seasonal distribution of maximum moisture to the south and southwest of the Tennessee Valley. From these analyses, it is apparent that the maximum persisting 12-hr dew point occurs in the months of June through September. It is at a maximum in July, but



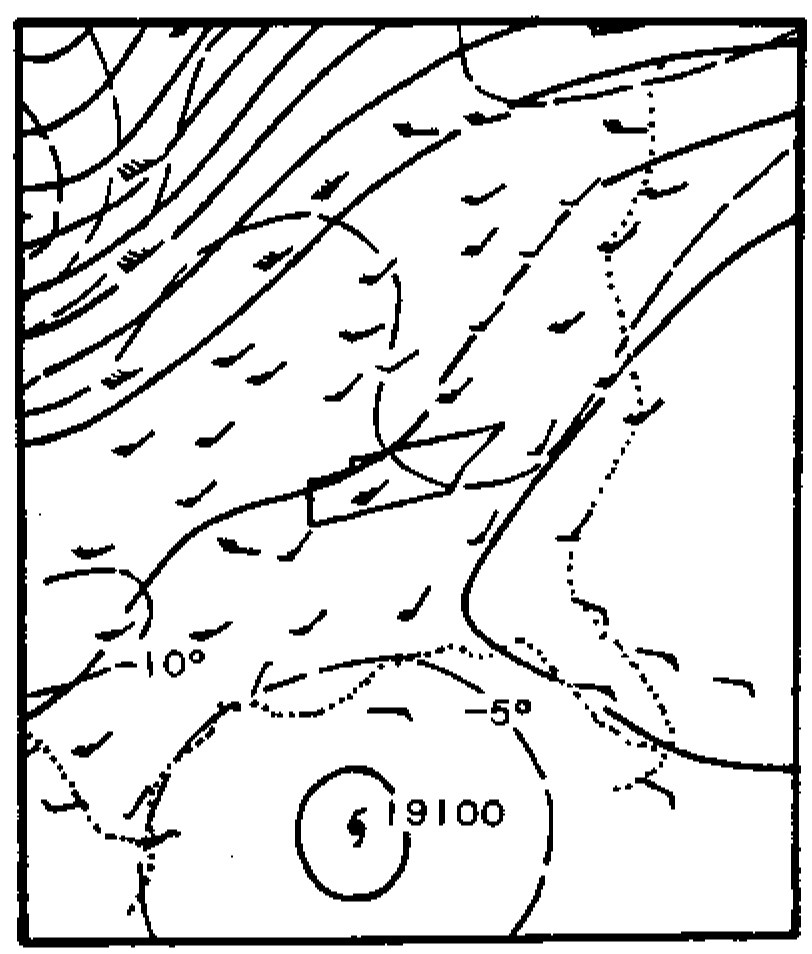
Sept. 30, 1964 Surface 1800GMT



Sept. 30, 1964 500mb 0000GMT



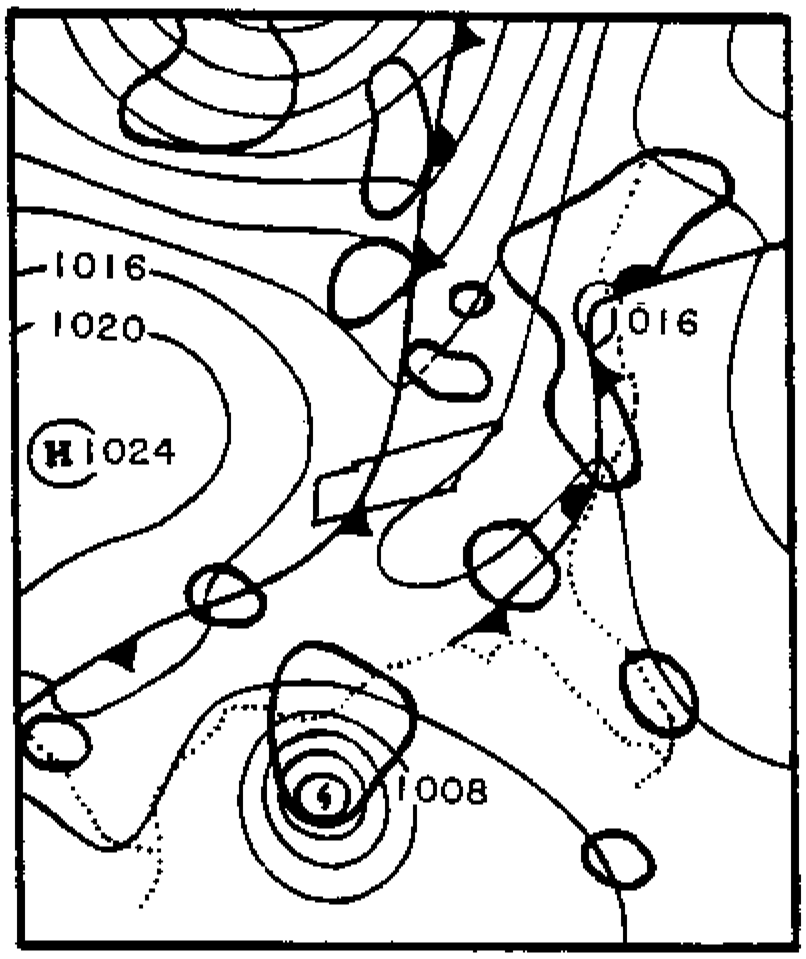
Oct. 1, 1964 Surface 1800GMT



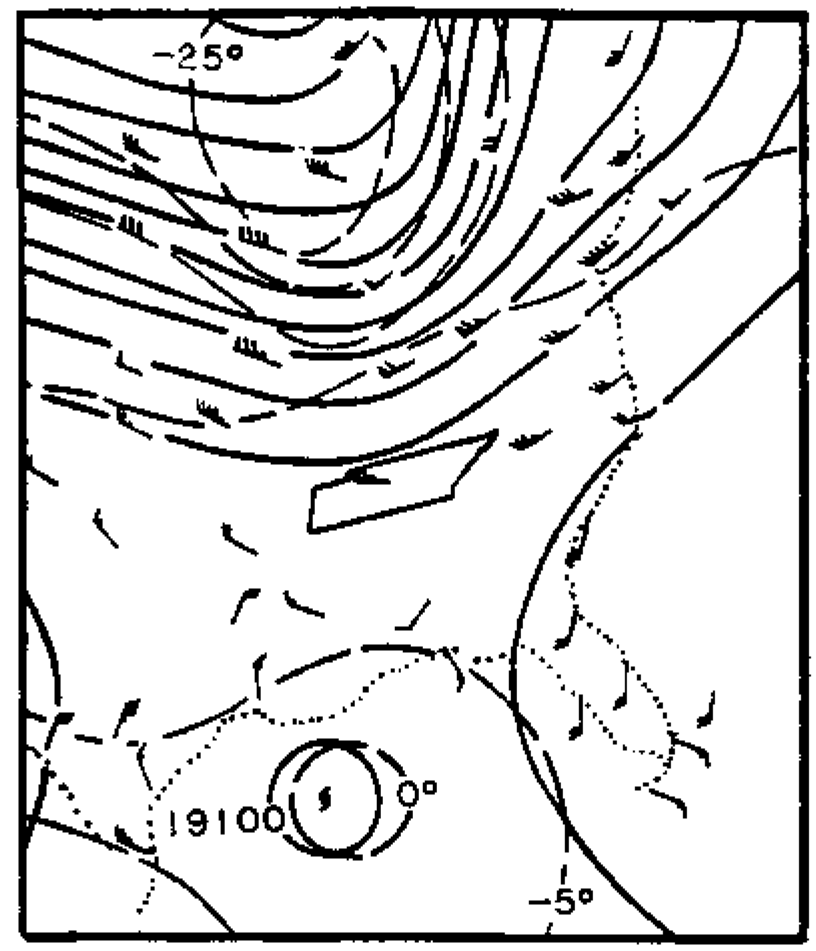
Oct. 1, 1964 500mb 0000GMT

Figure 45.—Surface and upper-air weather maps for September 30–October 1, 1964.

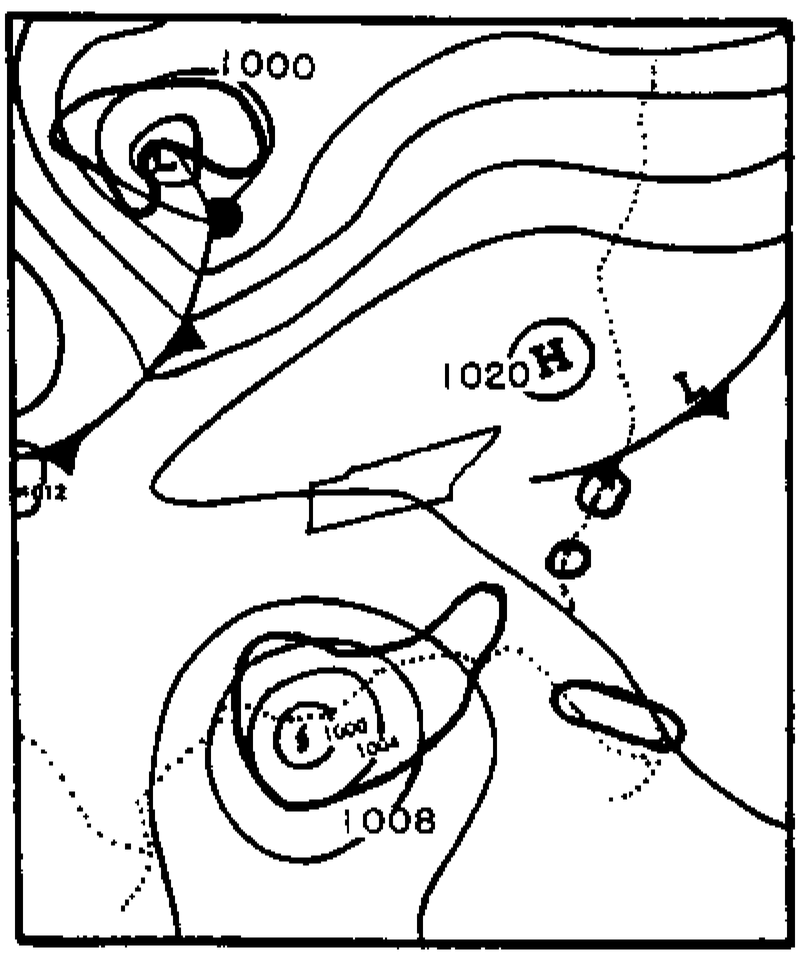
essentially the same from June to August. It decreases slightly from August to September. The approximate 100-yr precipitable water is at maximum from August to September. There is a small increase from July to August. June and October are at about the same level.



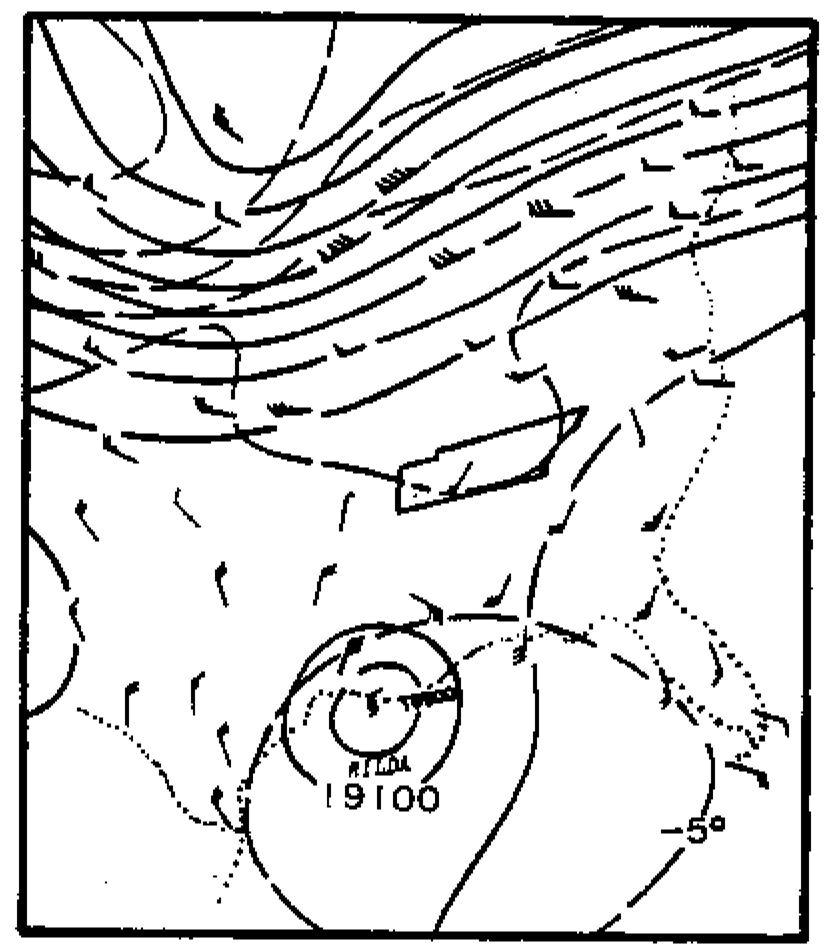
Oct. 2, 1964 Surface 1800GMT



Oct. 2, 1964 500mb 0000GMT



Oct. 3, 1964 Surface 1800GMT



Oct. 3, 1964 500mb 0000GMT

Figure 46.--Surface and upper-air weather maps for October 2-3, 1964.

3.3 Nonorographic PMP and TVA Precipitation

3.3.1 PMP Depth-Area-Duration Values

Estimates of probable maximum precipitation for basins between 100 and 3,000 mi^2 in the central and eastern United States are generally based on moisture maximization, transposition, and envelopment of storm values (Myers 1967 and Schreiner and Riedel 1978). Another method in which direct transposition was not used was applied in HMR No. 41 (Schwarz 1965) for estimating basic nonorographic PMP values for selected drainages between 8,000 and 21,000 mi^2

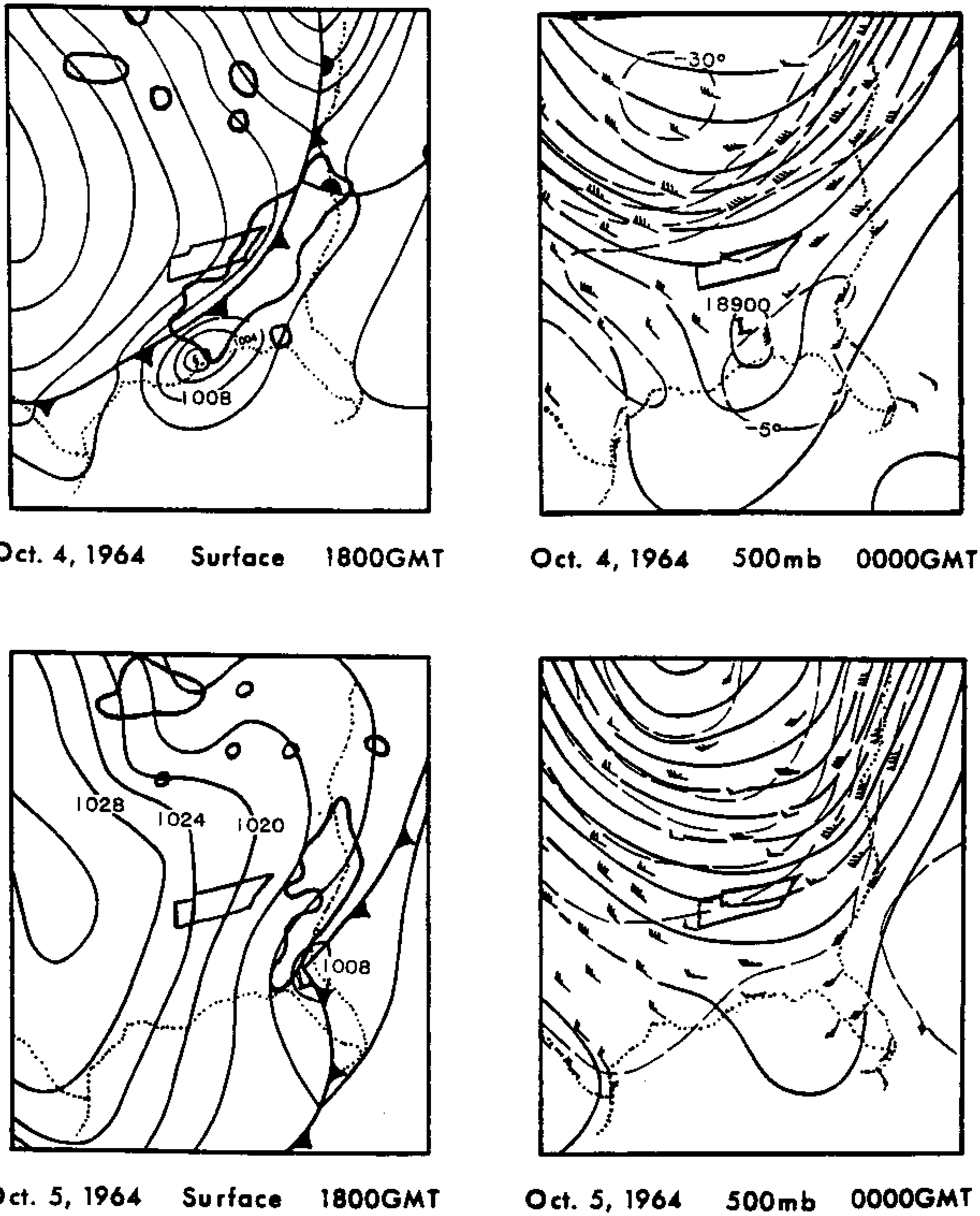


Figure 47.--Surface and upper-air weather maps for October 4-5, 1964.

above Chattanooga. In HMR No. 41, moisture-maximized values for selected area sizes and durations were plotted on maps at the various storm locations and enveloping isohyets constructed. Since actual storms are not directly transposed, it is only through regional, areal, and durational smoothing of the enveloped values that result in an implicit envelopment and transposition.

The same technique was used here. Analyses such as those in HMR No. 41 figure 5-3 cited above were constructed for a number of area sizes and durations. As an example, the analysis chart for 2,000 mi^2 and 24 hr is reproduced in figure 51. The basic data are listed in table 9. Note that the isohyets in figure 51

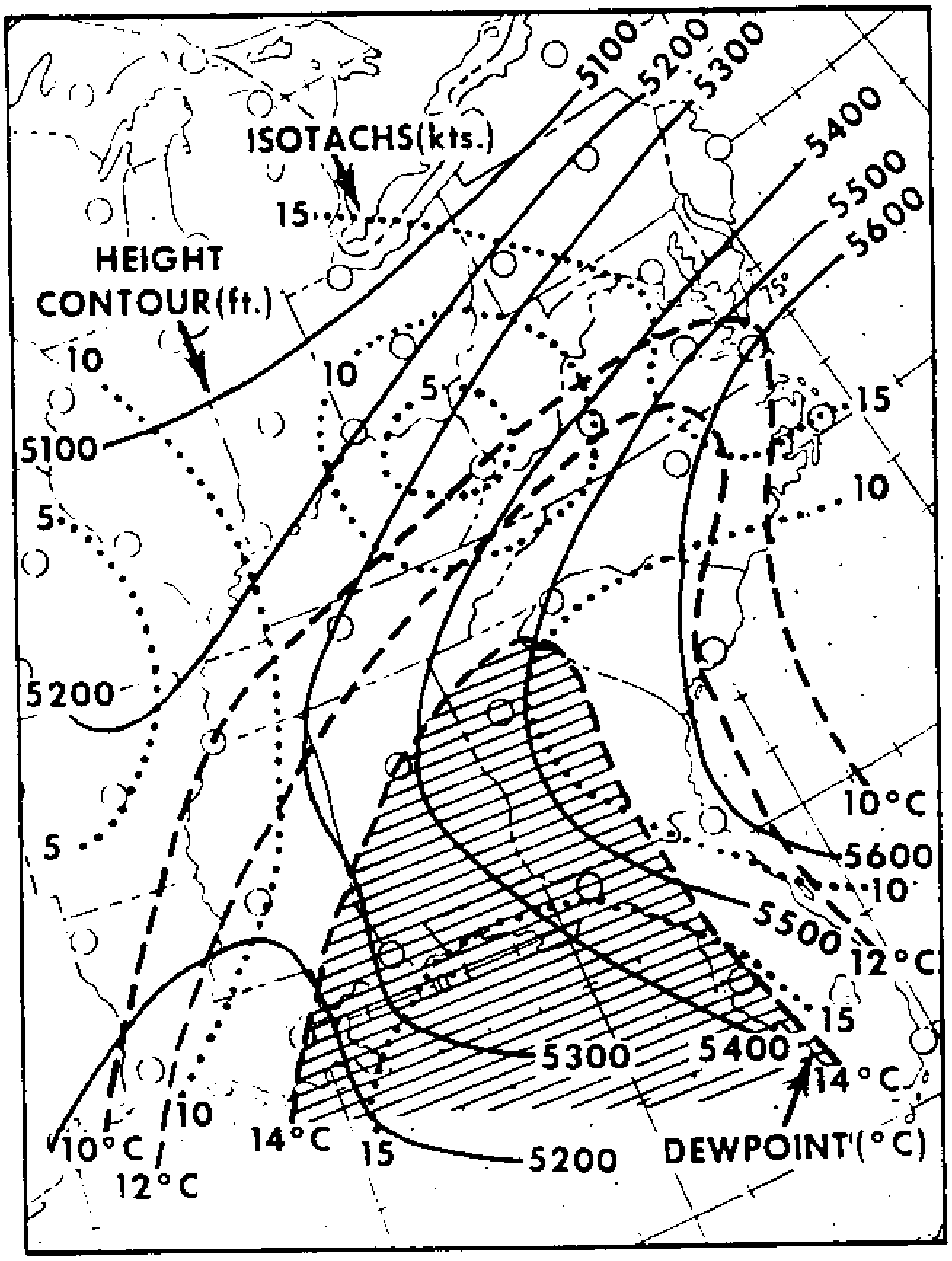


Figure 48.--Composite 850-mb (5,000-ft) chart for September 28-October 4. 1964.

represent a minimum envelopment of storms moisture maximized in place. (This map includes storms at all seasons while figure 5-3 of HMR No. 41 is only for the cool season.) Maps such as figure 51 need to be smoothed regionally, areally, and interdurationally before they can be regarded as PMP.

Scaling values from the final smoothed set of maps at Knoxville Airport leads to an array of basic PMP depth-area-duration values (fig. 52). In this figure, midwestern intense storms, particularly at Bonaparte, IA in June 1905 and at Hallett, OK in September 1940, have the biggest influence on the 6-hr values. Hurricanes exercise the most influence at intermediate durations; these include both the Gulf of Mexico hurricanes and the Jefferson, OH storm of September 1878, (a hurricane that passed from the Atlantic Ocean northwestward across the Appalachian Mountains).

Another type of storm from table 9 which had significant influence on Knoxville PMP values in figure 52 was the Elba, AL storm. This storm, which occurred over a 5-day period between March 11 and March 16, 1929, covered a 100,000-mi^2 area from Mississippi to South Carolina. The synoptic features of the storm were

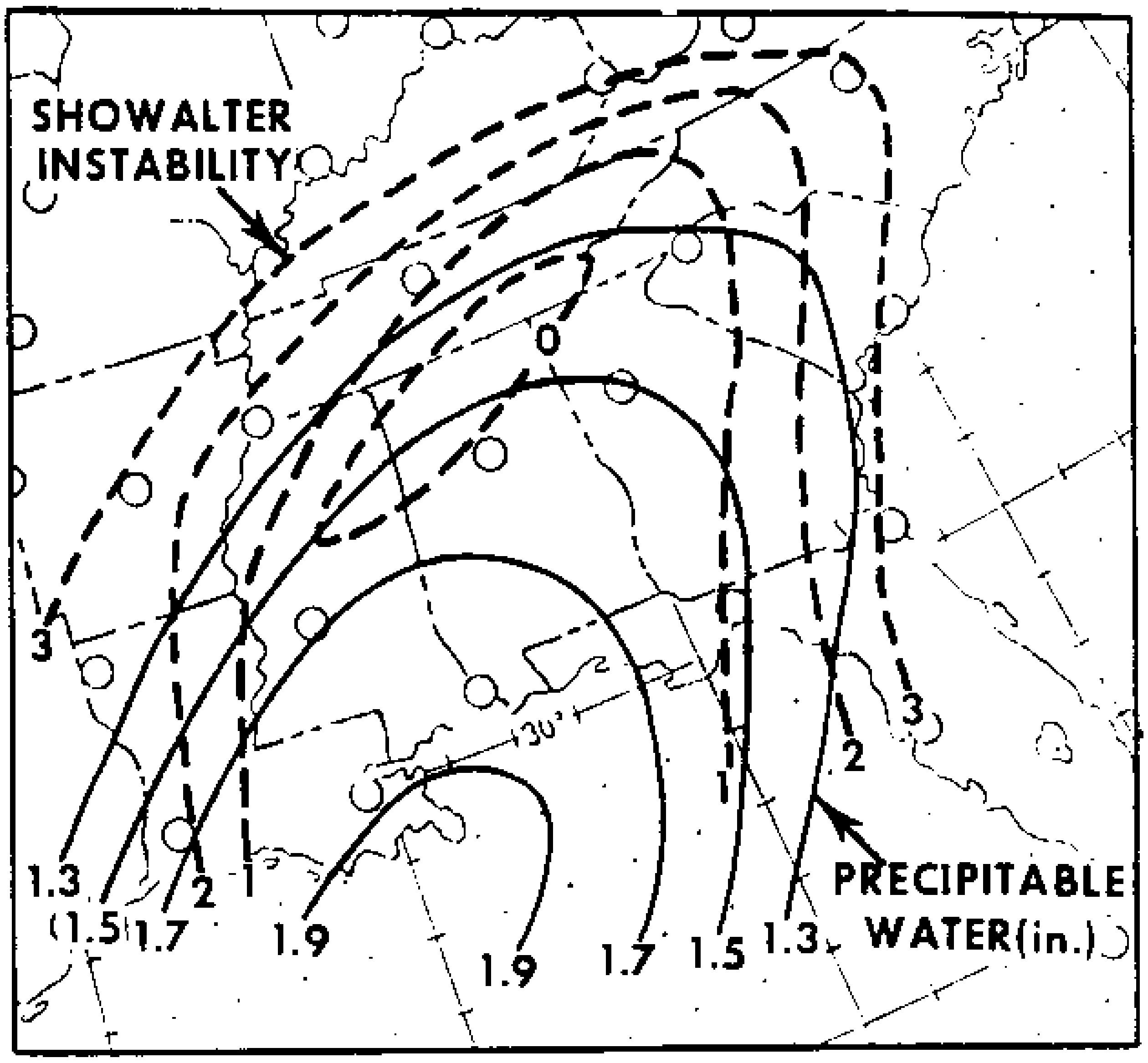


Figure 49.--Composite moisture-instability chart for September 28-October 4, 1964.

common to storms producing significant amounts of precipitation in early spring or early fall in the southeastern United States; namely a low pressure system associated with moist southerly flow colliding with cooler air to the north. Areas that are in the "warm sector" of these low pressure systems are especially susceptible to large amounts of precipitation; for example, in this storm Elba received nearly 30 in. of precipitation in almost 48 hr.

A table of PMP depth-area-duration values for the location of Knoxville Airport (from fig. 52) is shown in section 5.5.2 (p. 144). These values will be needed in the computational procedure for PMP, discussed in Chapter 5.

3.3.2 TVA Depth-Area-Duration Values

Figure 53 shows the basic TVA precipitation depth-area-duration values for the location of Knoxville Airport. These were derived in a manner analagous to the PMP values of figure 52, with omission of the moisture maximization step and with some undercutting of storm values that occurred at some distance from the Tennessee River basin. Depth-area-duration data for the July 5-10, 1916 hurricane (U.S. Army 1945-) have been adjusted by 0.70 (from fig. 5-4 HMR No. 41, Schwarz 1965), and are plotted in the diagram for comparison.

3.3.3 Basin-Wide Variation of Nonorographic PMP and TVA Depth-Area-Duration Values

The 24-hr 1,000-mi^2 isohyets (not shown), similar to figure 51, are converted to a percentage of values at Knoxville Airport, figures 54 and 55. The gradients of PMP and TVA precipitation for the basin sizes and durations that are the

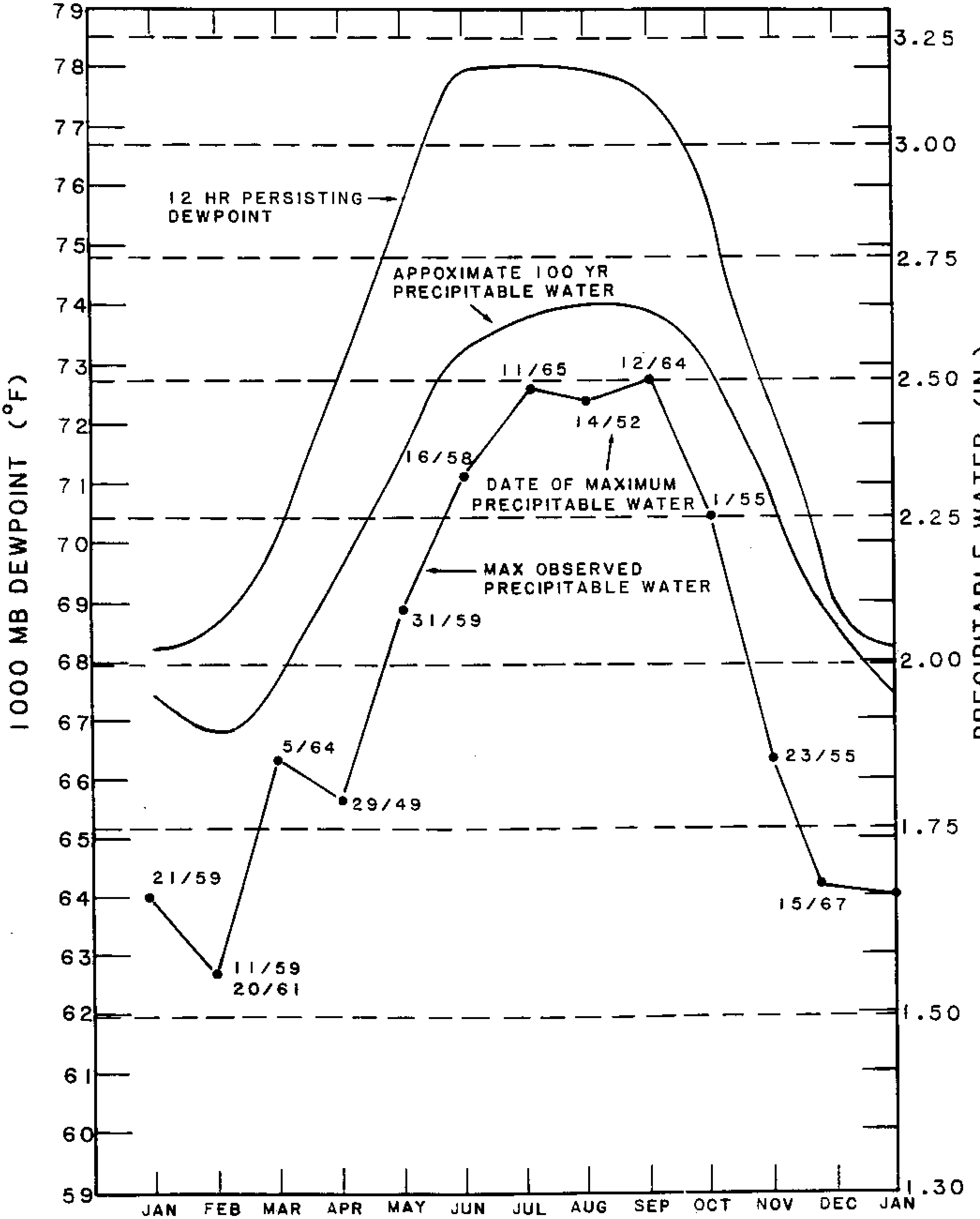


Figure 50.—Seasonal variation of maximum moisture, Montgomery, AL.

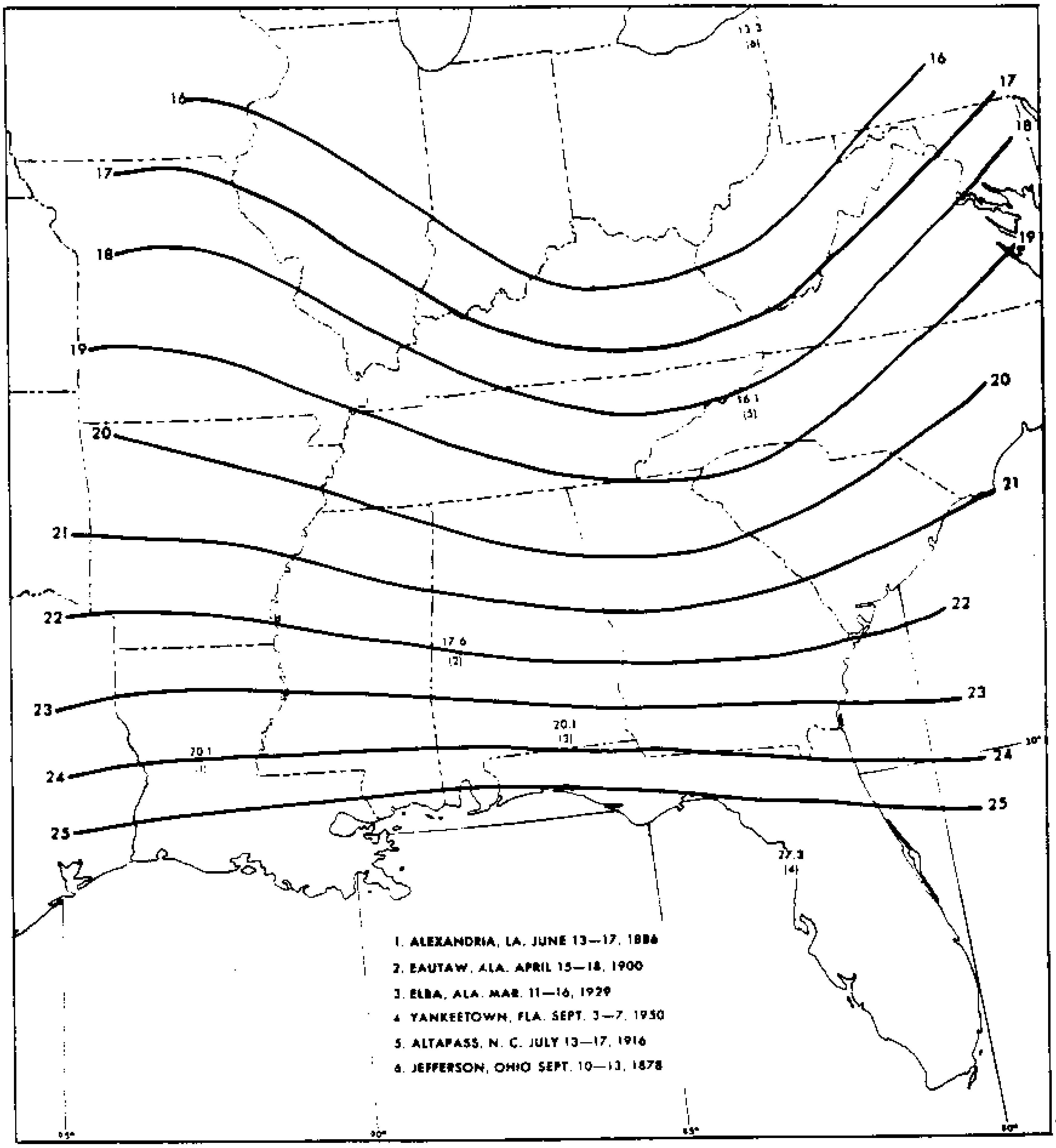


Figure 51.--24-hr 2,000-mi^2 PMP (in.).

subject of this chapter are relatively uniform over the Tennessee Valley. Figures 52 and 53 can be used as index charts for the full range of sizes ($\geq$100 mi^2) and durations ($\geq$6 hr covered in this report). Multiplication of the depth-area-duration values for PMP, (fig. 52) and for TVA precipitation (fig. 53) by the percentages shown in figures 54 or 55 yield respective nonorographic values throughout the basin.

Adjustments for orographic influences in the mountainous and nonmountainous eastern portion of the basin are described in sections 3.4 and 3.5. These sections also discuss effects of terrain roughness in adjusting the level of PMP and TVA precipitation in the entire Tennessee River Valley.

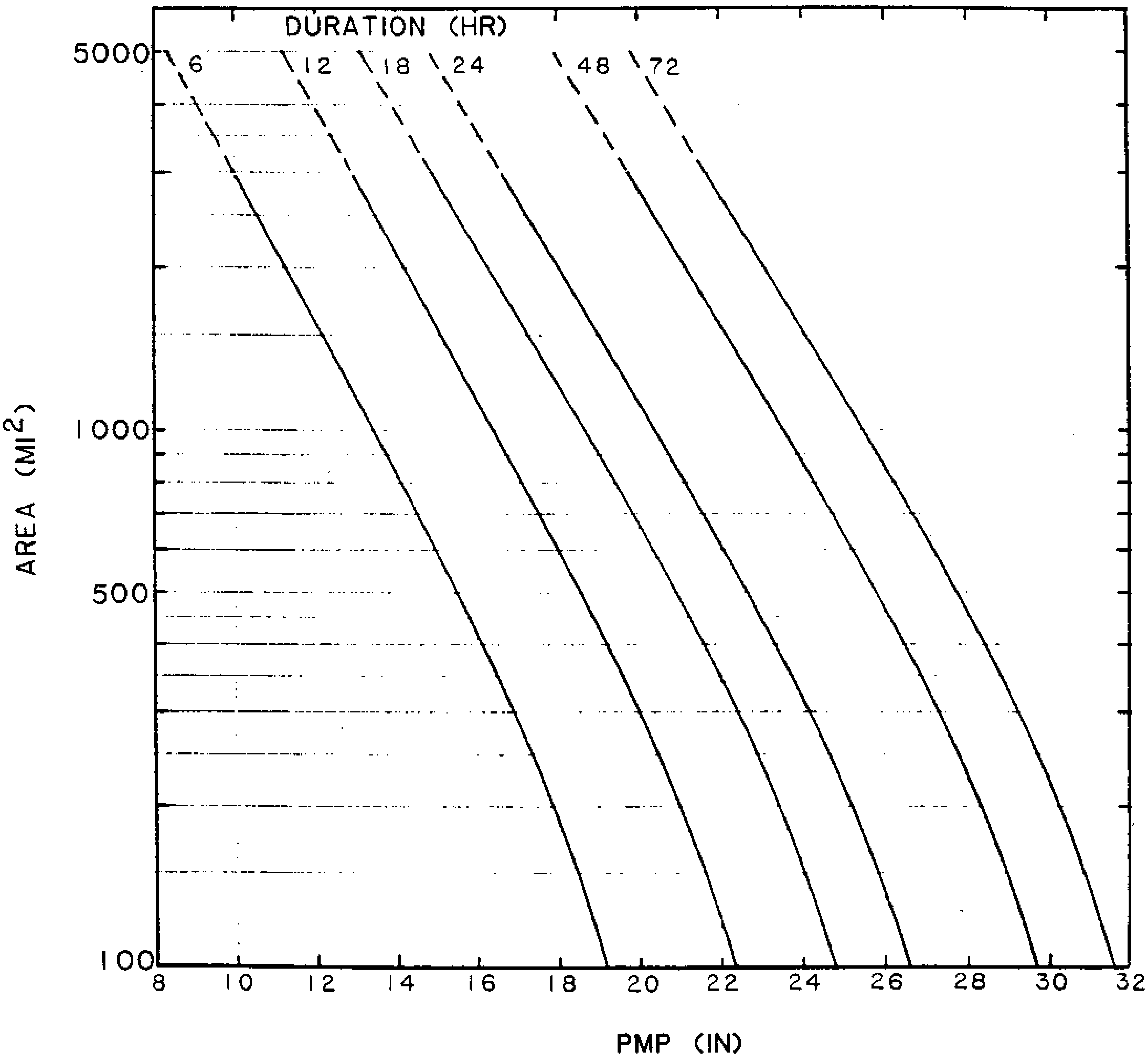


Figure 52.--Depth-area-duration curves for PMP at Knoxville Airport. Curves extrapolated from 3,000 to 5,000 mi^2.

3.4 Orographic Influence on PMP and TVA Precipitation

Five indicators of the orographic influence on the precipitation in the eastern part of the basin were developed to provide guidance in preparation of the generalized procedure and also the specific basin estimates given in chapter 6. These indicators are (1) mean annual precipitation, (2) 2-yr 24-hr precipitation frequency maps, (3) extreme monthly rains in subbasins, (4) small-basin PMP, and (5) optimum wind direction.

Table 9. Maximum observed and moisture-maximized storm rainfall for 24 hr over 2,000 mi^2

Date	Storm Center	Obs. Amt. (in.)	Moist.-Max Amt. in Place (in.)
9/10-3/13/1878	Jefferson, OH	10.4	12.7
6/13-17/1886	Alexandria, LA	17.3	20.1
6/27-7/1/1899	Hearne, TX	19.0	22.0
4/15-18/1900	Eutaw, AL	10.8	17.6
10/7-11/1903	Cortland, NY	10.2	15.1
8/28-31/1911	St. George, GA	11.3	13.7
3/24-28/1914	Merryville, LA	10.1	19.1
9/28-30/1915	Franklinton, LA	11.4	13.2
7/5-10/1916	Bonifay, FL	14.6	16.1
7/13-17/1916	Altapass, NC	13.3	16.1
9/8-10/1921	Thrall, TX	20.6	21.6
9/13-17/1924	Beaufort, NC	10.7	13.7
10/4-11/1924	New Smyrna, FL	11.9	14.4
4/12-16/1927	Jeff. Plaq. Drain. Dist., LA	13.3	16.2
6/1-5/1928	Thomasville, AL	10.9	14.0
9/16-19/1928	Darlington, SC	10.3	12.5
3/11-16/1929	Elba, AL	15.0	20.1
9/23-28/1929	Washington, GA	12.1	14.6
6/30-7/2/1932	State Fish Hatchery, TX	16.9	19.6
8/30-9/5/1932	Fairfield, TX	12.8	14.1
7/22-27/1933	Logansport, LA	13.0	14.3
12/5-8/1935	Satsuma, TX	11.9	18.6
6/27-7/4/1936	Bebe, TX	12.2	12.2
9/14-19/1936	Broome, TX	11.6	12.2
8/6-9/1940	Miller Island, LA	16.7	18.6
9/2-6/1940	Hallet, OK	10.7	15.1
10/17-22/1941	Trenton, FL	15.2	17.6
7/17-18/1942	Smethport, PA	10.2	11.2
9/3-7/1950	Yankeetown, FL	24.8	27.3
6/23-28/1954	Vic Pierce, TX	14.7	17.1
9/19-24/1967	Falfurrias, TX	10.4	12.1
8/19-20/1969	Tyro, VA	10.9	11.4
6/19-23/1972	Zerbe, PA	11.4	13.8

3.4.1 Mean Annual Nonorographic and Orographic Precipitation

Figure 56 is a mean annual precipitation chart for the Tennessee River basin (Tennessee Valley Authority, 1969). To indicate the influence of orography on the mean annual values, a hypothetical mean annual nonorographic precipitation chart is needed. Such a chart is shown in figure 57 and is derived by extrapolating mean annual precipitation values from areas outside the immediate

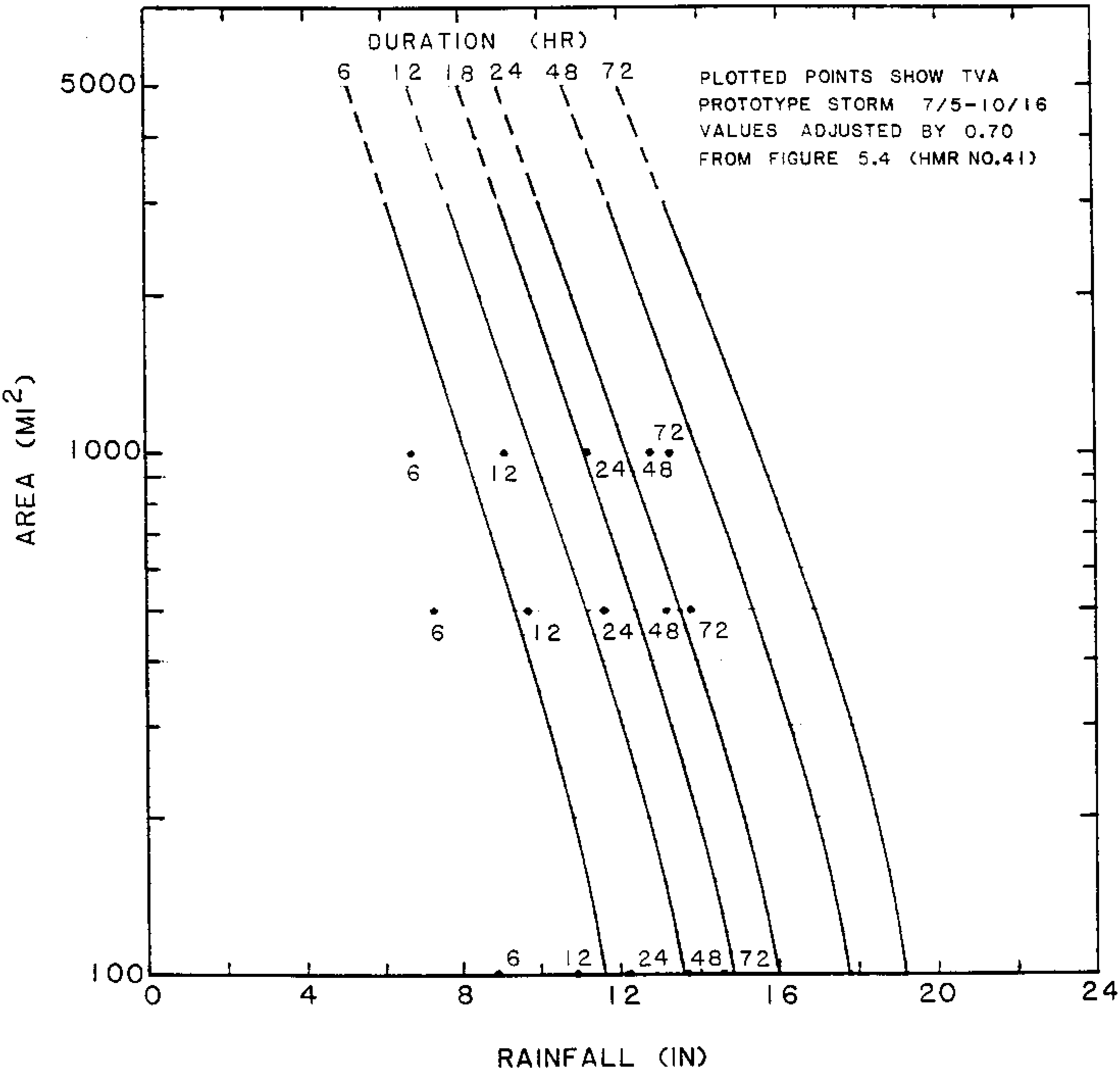


Figure 53.--Depth-area-duration curves for TVA precipitation at Knoxville Airport. Curves extrapolated from 3,000 to 5,000 mi^2.

influence of the Appalachian chain across the Tennessee Valley region. The orientation of the isohyets agrees fairly well with that of the generalized PMP percentile lines of figure 54. Comparison of figures 56 and 57 provide one measure of the generalized orographic effect in a particular basin.

For 18 specific basins in the eastern portion of the Tennessee River watershed, ratios between the basin-average mean annual precipitation and the basin-average mean annual "nonorographic" precipitation were computed (see table 4-2, items 4, 5, and 6 of HMR No. 45.) These ratios are one measure of the generalized orographic effect in a basin related to the distribution of primary upslopes,

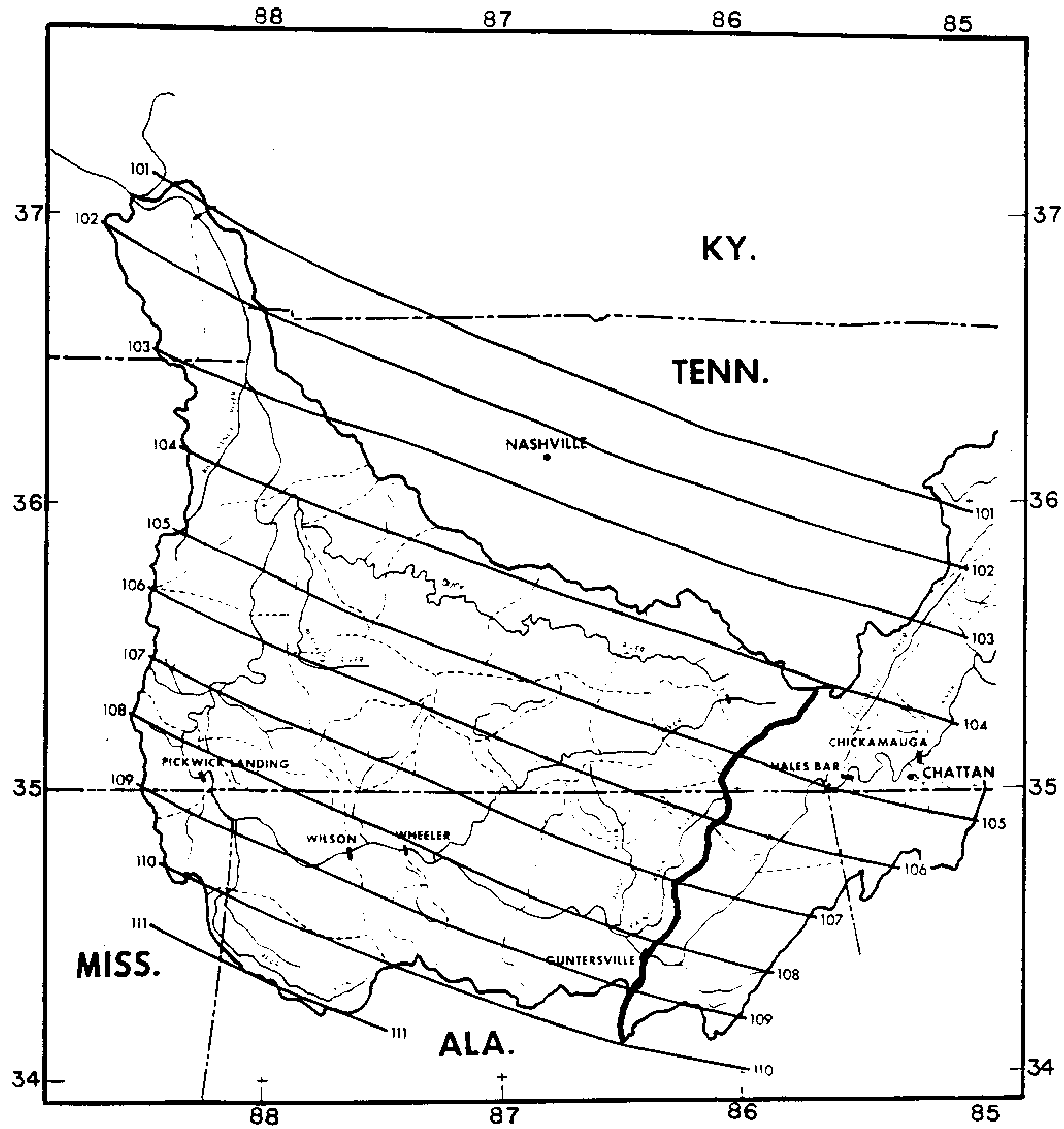


Figure 54.--24-hr 1,000-mi^2 PMP and TVA precipitation percentiles of Knoxville Airport for the western portion of Tennessee River watershed (note overlap of eastern region in fig. 55).

secondary upslopes, and sheltered areas within the basin (refer to sect. 2.2.4 for the definition of primary and secondary upslopes and sheltered areas, and to figure 14 for the distribution of these topographic features in the eastern part of the watershed). In other words, the variation of the ratios between average mean annual precipitation and average mean annual nonorographic precipitation over the eastern part of the watershed is related to the distribution of these three types of topographic features.

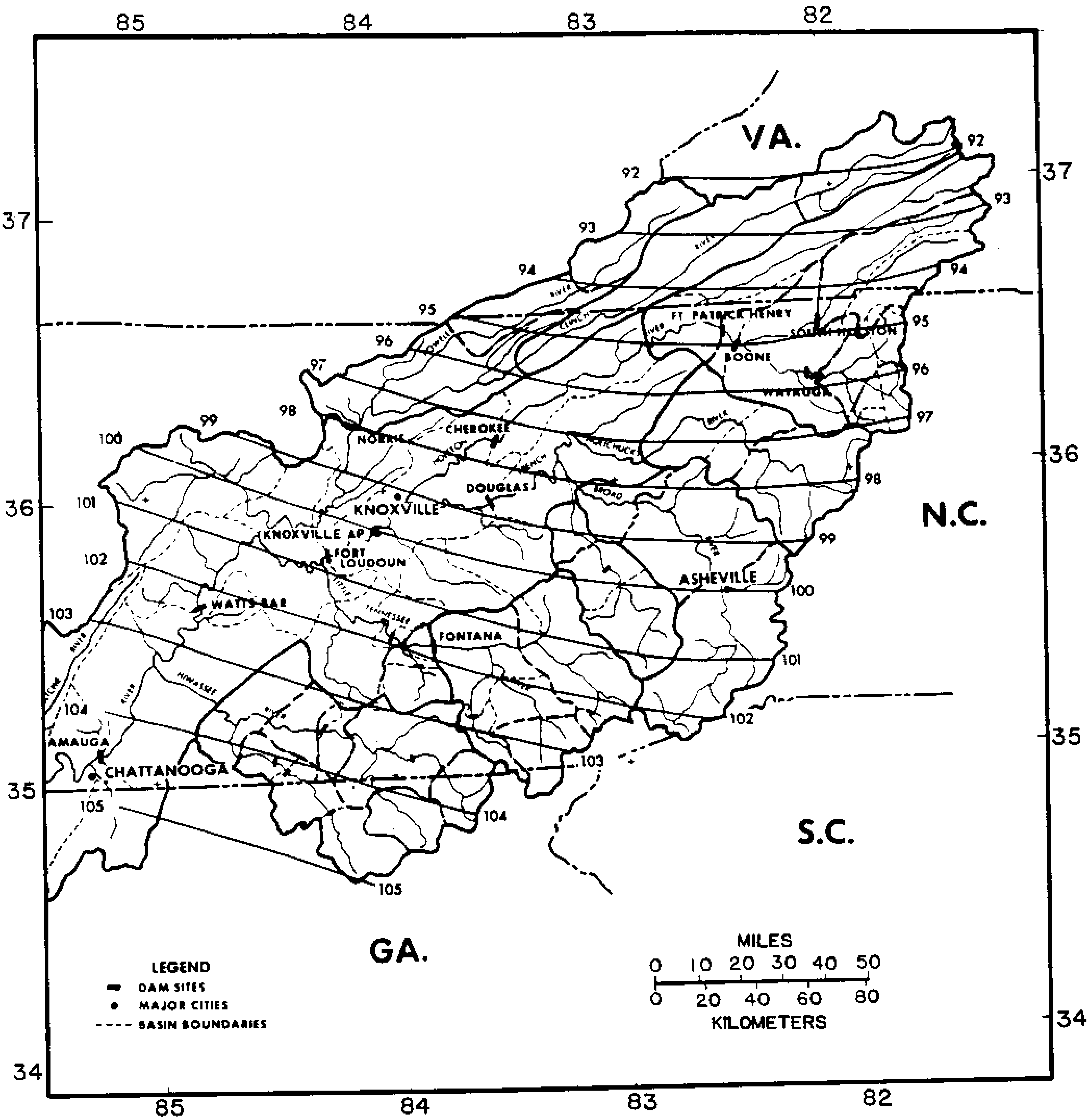


Figure 55.--24-hr 1,000-mi^2 PMP and TVA precipitation percentiles of Knoxville Airport for the eastern portion of Tennessee River watershed.

In order to develop a procedure for estimating the broadscale orographic factor (BOF) for each of the 18 basins (shown in fig. 100) for which estimated orographic ratios were given in table 4-2, item 7, of HMR No. 45, percentages of primary upslopes, secondary upslopes, and sheltered areas in the basins were computed. These respective percentages were then related via a regression analysis to the estimated ratios. The regression analysis indicated a correlation of 0.98 (standard error of estimate of 0.03) between the percentages and ratios. The regression analysis also gave "least squares" coefficients for relating the BOF and the percentage of primary upslopes, secondary upslopes, and sheltered areas. This is shown in equation form:

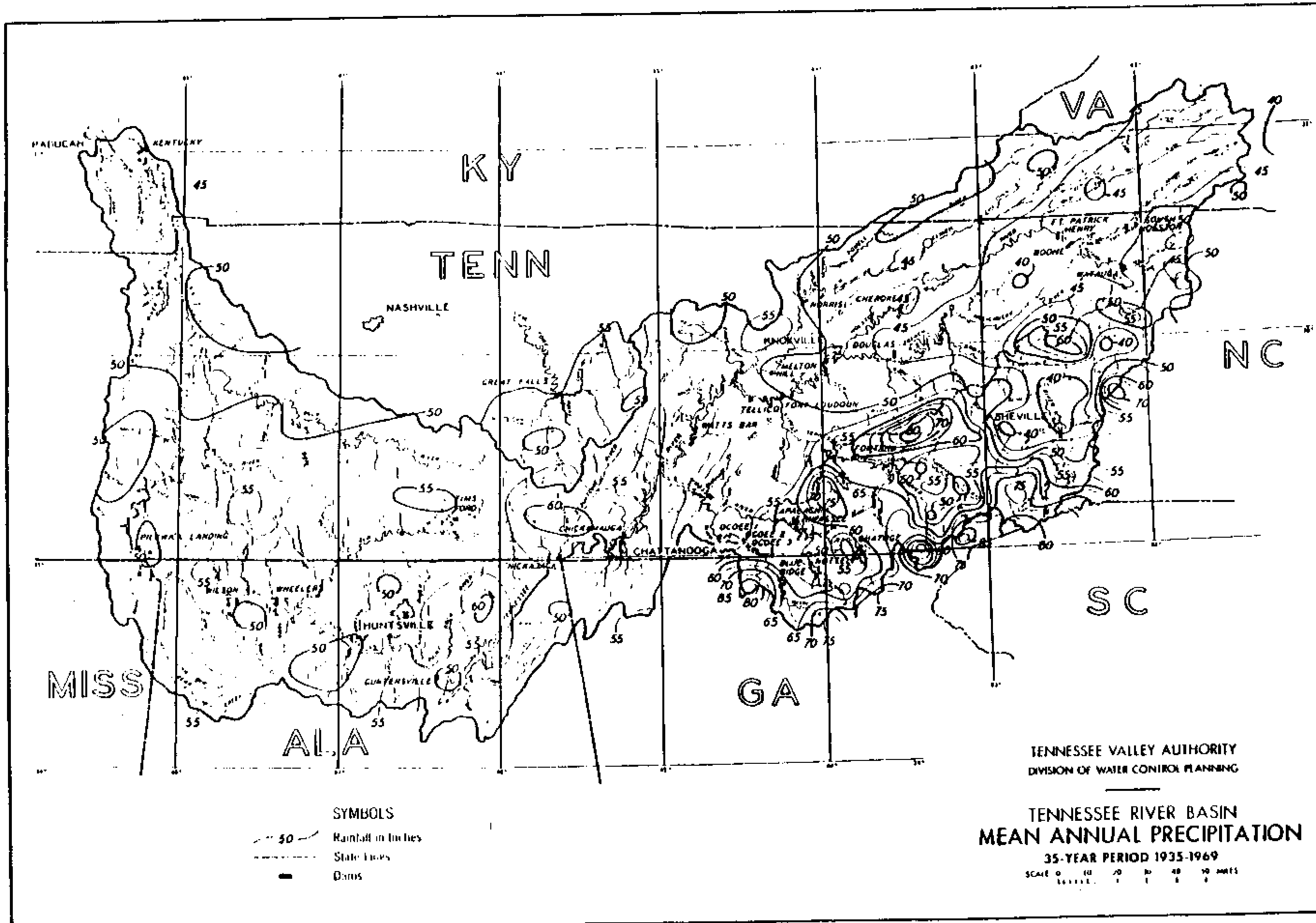


Figure 56.--Mean annual precipitation (in.) for the entire Tennessee River watershed.

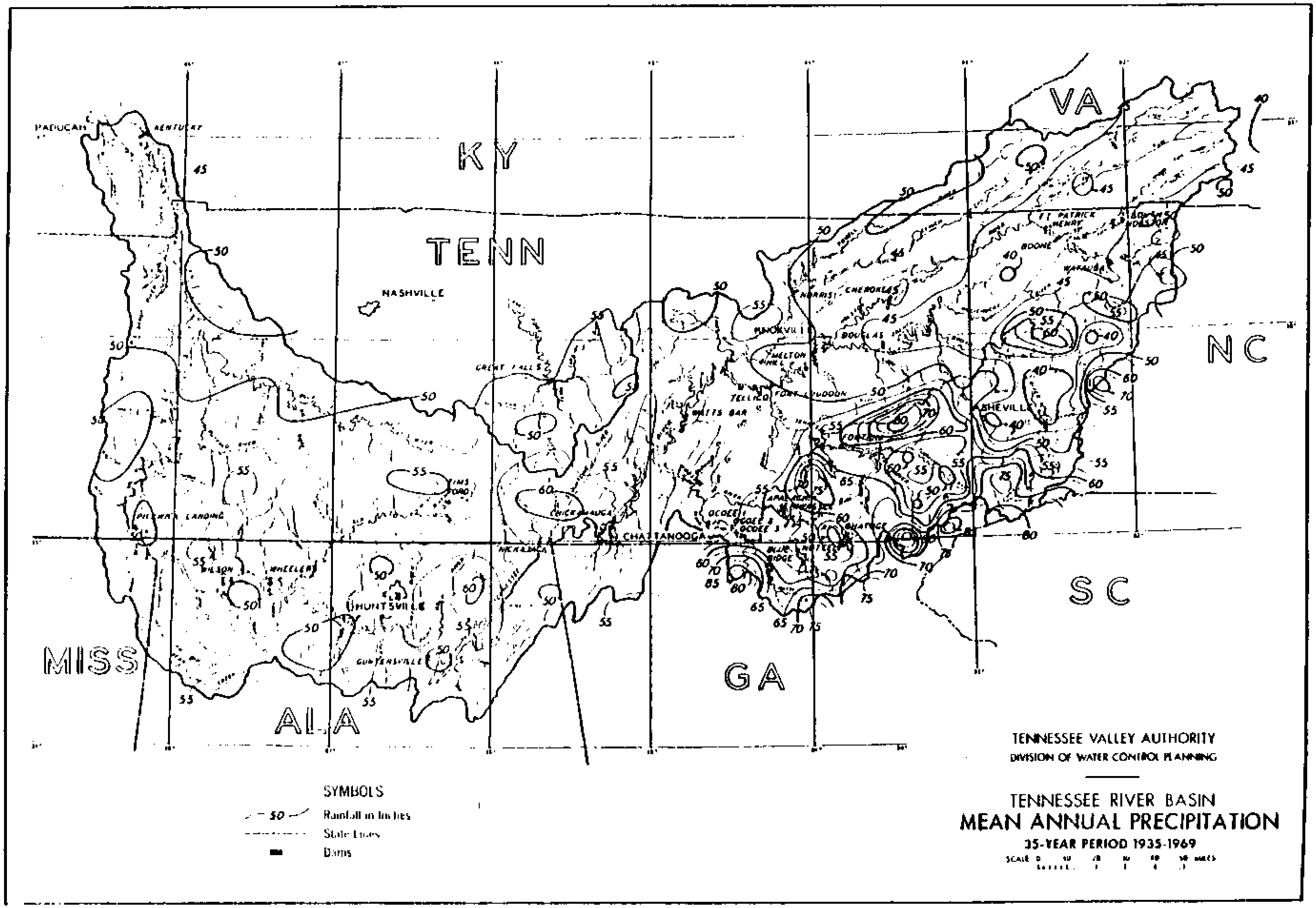


Figure 56.--Mean annual precipitation (in.) for the entire Tennessee River watershed.

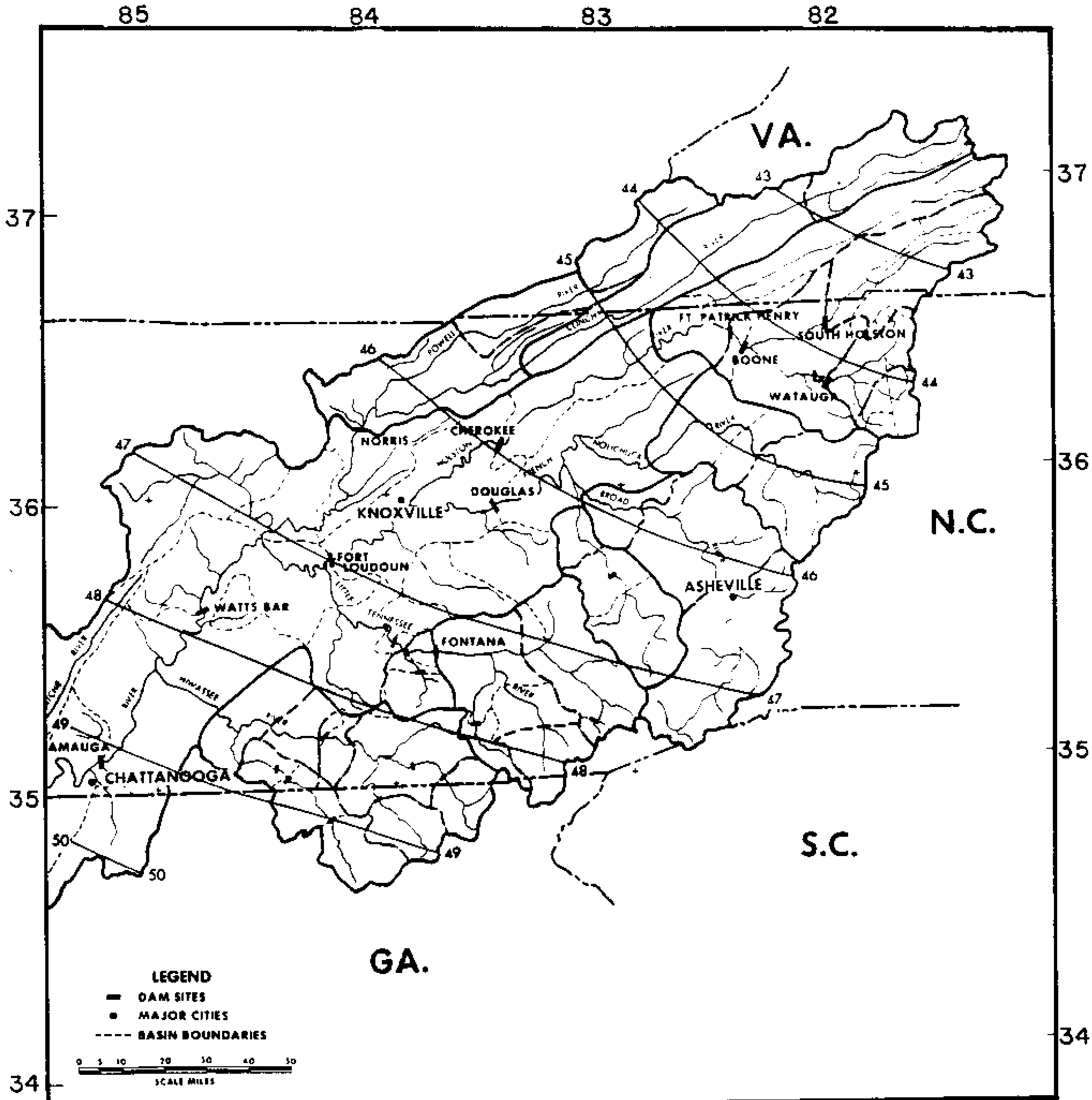


Figure 57.--Nonorographic component of the mean annual precipitation (in.) for the eastern Tennessee River watershed.

$$\frac{\text{Average mean annual precipitation}}{\text{Average mean annual "nonorographic" precipitation}} = \text{BOF} = .55 \times (\%\ \text{primary upslopes}) + .10 \times (\%\ \text{secondary upslopes}) + .05 \times (\%\ \text{sheltered areas})$$

The final number should be rounded to the nearest 0.05 to give the BOF, which will be used in evaluating the total PMP in chapter 5.

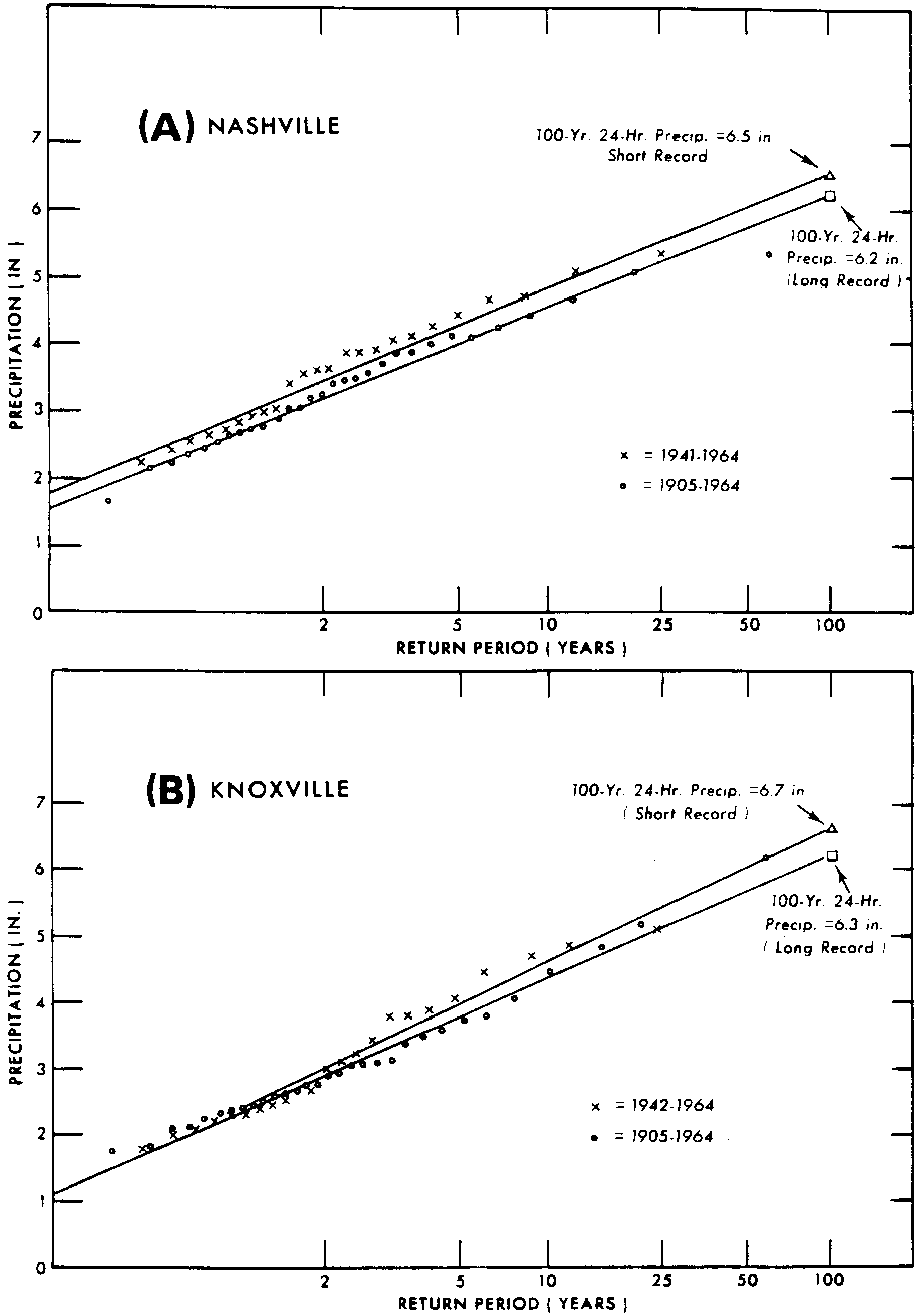


Figure 58.--Rainfall-frequency curves for (A) Nashville and (B) Knoxville, TN.

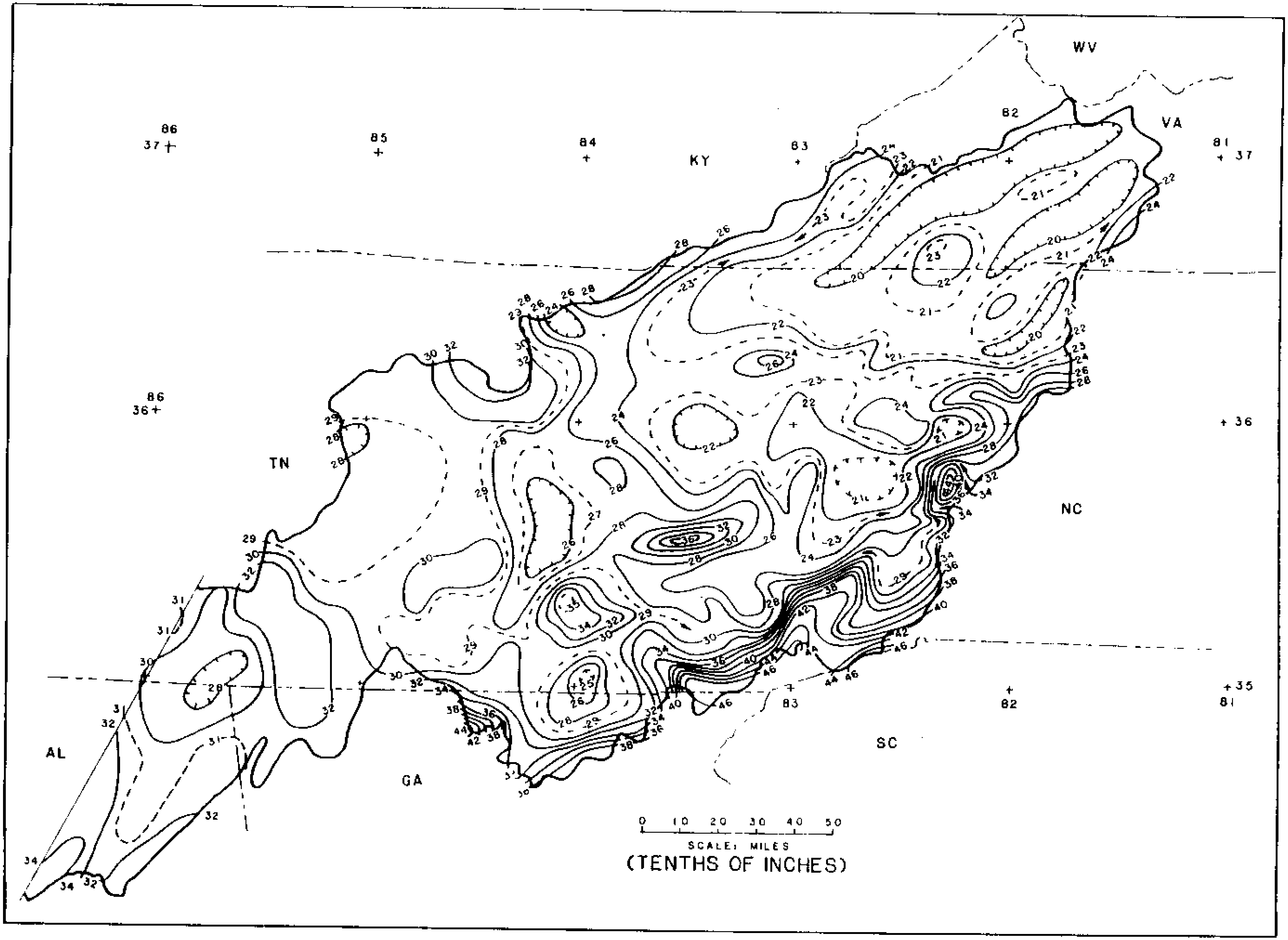


Figure 59.—2-yr 24-hr precipitation (in.) analysis - eastern Tennessee River watershed. Note that all values have been multiplied by 10.